CONSUMER ATTITUDES OF PREDICTED FLAVOR AROMAS IN STEAKS CREATED WITH DIFFERENT STEAK THICKNESSES, QUALITY GRADES, AND COOKING SURFACE TEMPERATURES

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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December 2015

Major Subject: Animal Science

ABSTRACT

Levels of positive and negative beef flavors attributes were created by cutting USDA Top Choice and Select beef top loin steaks to 1.3 cm or 3.8 cm thicknesses and cooking on a commercial flat top grill at 177˚C or 232˚C. The thickness and temperature combination was designed to maximize differences in the development of Maillard reaction products and lipid thermal degradation products in the steaks. A trained descriptive attribute panel, consumer sensory panel, and gas chromatography/mass spectrophotometry with an olfactory port were used to evaluate steaks.

As thickness and temperature increased, beef identity and brown/roasted flavor aromatics increased. The thickness and temperature interaction had the greatest impact on beef flavor attributes. Steaks cooked at 232˚C and cut 3.8 cm thick had the highest levels of burnt flavor and bitter basic tastes. Thicker steaks cooked at 177˚C had higher levels of umami basic taste and higher levels of positive beef flavor attributes. Steaks cut 1.3 cm thick had lower levels of brown/roasted and beef identity flavor aromatics than the 3.8 cm cut steak cooked at 177˚C. Thickness by quality grade interaction was significant for liver-like and brown/roasted flavor attributes. Temperature by quality grade was significant for the salty beef flavor attribute. Consumers rated 232˚C, 3.8 cm steaks lowest for overall, beef flavor, overall flavor, and grilled flavor liking, whereas the 177˚C, 3.8 cm steaks were highest in beef flavor.

Volatile aromatic compounds were used to calculate regression equations for beef flavor identity, brown/roasted, bloody/serumy, fat-like, metallic, liver-like, and

umami, which accounted for 51, 55, 30, 35, 53, 87, and 24 percent of the variability, respectively, in beef flavor descriptive attributes. Eighteen volatiles accounted for 22 percent of consumer overall liking. Partial least square means regression biplots identified volatiles associated with flavor attributes and treatments. Phenyl acetaldehyde was most closely grouped with consumer overall liking.

It is important to study cooking method as it is related to thickness and temperature to determine what factors drive the production of positive beef attributes as well as negative attributes. Little research has been done on thickness and temperature effect on beef steak flavor and how they drive the production of aromatic compounds. With the consumer being influenced more and more by flavor, it is key to study the effect of temperature and thickness on the development of flavor and the aromatic compounds related to positive flavor.

DEDICATION

This work is dedicated to my family, friends and colleagues who have supported me and formed me into the person I am today.

ACKNOWLEDGEMENTS

Thank you to the National Cattlemen's Beef Association for funding this project and their unwavering drive to improve beef flavor, consumer knowledge, and the beef industry as a whole. #EatBeef

Thank you to my committee, Dr. Kerth, Dr. Savell, and Dr. Miller, as well as all the other professors who helped and offered guidance throughout the project. Thank you Dr. Savell for giving me this wonderful opportunity to come to grad school and be a part of the extension, teaching, and learning activities. A special thank you goes to Dr. Kerth and Dr. Miller for believing in me and giving me such a fun but intensive research project. I learned more than I thought I would and sometimes more than I wanted to. Thank you to Dr. Kerth for always having an open door to help me with my thesis, just talk, or hang out; I have had tons of fun with you on our trips or various other activities during my time at Texas A&M. Dr. Kerth has made my time in grad school fun and enjoyable. Thank you to Dr. Miller for always being there for me no matter what and knowing that we are here for her. Dr. Miller is a great mentor, has a brilliant mind, is 110% invested in each and every student of hers and wants them to succeed in everything they do. Thank you to both Dr. Miller and Dr. Kerth for allowing (and making) us travel across the country whether it was for research, a conference, or a meat science activity. I was able to learn so much and meet so many important individuals as well as see many interesting things, such as Yellowstone, that will forever benefit me in my life. Additionally, thank you to Dr. Adihikari for helping on all the research trips

and serving all the samples. Dr. Adihikari's help was priceless and it was great getting to know him, he is a brilliant individual.

A huge thank you goes out to my fellow graduate students throughout the Animal Science Department but specifically in the Meat Science Section. Thank you to Rosenthal and all the workers and student workers especially Mark and Pudge for dealing with our massive quantities of meat and broken equipment. But most importantly, thank you to Hannah and Tanner for being road warriors with me and traveling the country driving probably over 15,000 miles for our projects. You two made it a fantastic time and I loved having you along; I wouldn't trade it for anything.

Thank you to my family: my brothers Kevin and Connor; sisters Sophie and Gigi; stepmom Colleen; my mother Colleen and father Doug. Thank you for forming me into the person I am. You have always been my biggest supporters and taught me to be the best I can be and to strive for greatness. Thank you for giving me all the opportunities you have and the constant love and support. You are my motivation to be the best I can be everyday and to make a difference in everything I do.

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CHAPTER I

INTRODUCTION

Uncooked meat has little to no aroma with only a bloody/serumy taste (Mottram, 1998) and thus must be heated/cooked for flavors to develop. For this reason, the cooking process and the state of the meat that is being cooked is so crucial for positive flavor development. The beef industry has been constantly researching consumer preference and liking to determine what drives consumer desire. Traditionally, tenderness has been the driving factor for consumers and has been the key factor researched (Belk, Luchak, & Miller, 1993; Brooks et al., 2000; Cross, Carpenter, & Smith, 1973; Guelker et al., 2013; Hunt et al., 2014; Sherbeck, Tatum, Field, Morgan, & Smith, 1996), but now consumers are driven by primarily flavor (Kerth & Miller, 2015; Legako et al., 2015; Miller, 2001). Lately, research has been focused on the flavor chemistry of the beef via the study of aromatic volatile compounds that are produced and linking them to flavor attributes or cooking methodology (Glascock, 2014; Kerth & Miller, 2015; Legako et al., 2015; Luckemeyer, 2015; Miller & Kerth, 2012; Mottram, Edwards, & Macfie, 1982).

The study of the flavor components is crucial because beef flavor is not a "single" attribute, but are multiple attributes that are ever evolving and are affected by both internal and external forces. The beef industry took the first big step in addressing beef flavor by funding the development of the beef flavor lexicon (Adhikari et al., 2011) that identified major and minor beef flavor descriptors. The development of this lexicon

enabled the identification of the flavors present and their intensity. Without this universal scale it would be near impossible to identify what flavors make up beef flavor and how we perceive it.

Miller and Kerth (2012) looked further into beef flavor by determining that multiple chemical compounds contributed to each attribute and then comprised data to more closely identify key aromatic, volatile flavor compounds in future studies. Glascock (2014) and Luckemeyer (2015) identified groups of volatile flavor compounds that may help to identify what compounds can be used to drive flavor differences as well as identifying compounds that cluster together. By understanding what chemical compounds are responsible for specific beef flavor attributes, they can be used to regulate beef flavor by driving the production of positive compounds and inhibiting the formation of negative attributes.

One hypothesized method to control the formation of volatile compound is to manipulate the grill temperature and the steak thickness. Kerth, Hesteande, and Luckemeyer (2013) examined different levels of Maillard reaction products on steaks that were cut to different thicknesses and grilled at different temperatures. Kerth et al. (2013) showed that varying the levels of steak thickness and cook surface temperatures to a consistent degree of doneness created aromatic volatiles that were characteristic of various beef lexicon descriptors, and that different thicknesses and temperature affected the compounds formed.

The objective of this project was to create varying levels of beef flavor by cutting Top Choice and Select top loin steaks 1.3 cm or 3.8 cm thick and cooking them at either

177°C or 232°C. Cuts were evaluated using an expert trained meat flavor panel, consumer panels, and volatile compounds were measured using GC/MS/O to explain the chemicals in beef flavor. Fatty acid composition, non-heme iron content, myoglobin content, pH, and fat and moisture analysis were determined and correlated to chemical properties of the raw beef to the flavor of the cooked beef. This allowed consumer positive and negative flavor attributes to be tied with the trained panel beef lexicon, and volatile aromatic compounds that contribute to beef flavor.

It was hypothesized that by using the different thicknesses and temperatures, the resulting time and temperature combination during cooking would create differing levels of flavor in Top Choice and Select beef top loin steaks as well as produce differing volatile compounds.

CHAPTER II

LITERATURE REVIEW

Biological Response to Flavor

Taste and smell are responsible for evaluating the food we eat, and in the world around us, these senses have developed to enable our survival and determine our preferences. The attributes of a food item are perceived in the order of: appearance, odor/aroma, consistency and texture, and flavor (Meilgaard, Carr, & Civille, 2007). These attributes overlap and provide multiple stimuli that contribute to the overall eating experience for the item. For sensory purposes, flavor is defined as, and measured as, the combined impressions perceived via the chemical senses from a product in the mouth (odor/aroma, and flavor), eliminating appearance and texture from the observation (Meilgaard et al., 2007). In the mouth, the senses of olfaction and gustation combine to produce flavor perception (Small, Jones-Gotman, Zatorre, Petrides, & Evans, 1997). Since these two senses are tied together for the detection of flavors; if one is inhibited the perception of flavor will be greatly diminished.

Although we can taste a vast array of chemicals, it is now generally accepted that, qualitatively, they evoke few distinct taste sensations: sweet, bitter, sour, salty, and umami (Chandrashekar, Hoon, Ryba, & Zuker, 2006). Gustation is responsible for the detection of these tastes by receptors in the mouth on the tongue and throat by the detection of soluble chemicals dissolved in water, oil or saliva (Meilgaard et al., 2007). Sweet taste permits the identification of energy-rich nutrients, umami allows the

recognition of amino acids, salt taste ensures the proper dietary electrolyte balance, and sour and bitter warn against the intake of potentially noxious and/or poisonous chemicals (Chandrashekar et al., 2006). Importantly, taste has the additional value of contributing to the overall pleasure and enjoyment of a meal. Traditionally it was thought that the tastes were identified in key locations on the tongue, but now research is suggesting that there are no distinct areas and that each basic taste is detected through out the surface of the tongue (Yamamoto, Yuyama, Kato, & Kawamura, 1984). Instead, taste receptor cells (TRC) are located throughout the tongue and each have a unique chemical/flavor they are coded and detect for. Gustatory senses have no risk of being immersed during tasting unlike olfactory senses since they are bathed in the solution, however, there is high risk of over saturation (Meilgaard et al., 2007). When tasting, a few sips should be taken and only left in the mouth for a couple of seconds and a break of 15-60 seconds between samples as over-saturating could result in binding to the taste receptor cells inhibiting their ability to function properly and detect tastes.

Olfactory senses are responsible for detecting aromatic or volatile compounds. These odors are a lot less defined and straightforward than gustatory senses and take training to identify and detect because there are thousands of possible smells (Meilgaard et al., 2007). Olfactory and gustatory senses have a synergistic effect enhancing each other and without either one person's ability to detect flavors will be drastically impaired. Several tens of millions of olfactory sensory neurons are distributed over the epithelium, individual sensory neurons extend a single dendrite to the surface of the epithelium which then extend several cilia into the mucus layer of the epithelium (Mori

& Yoshihara, 1995). Odorant molecules are detected by these millions of tiny hair-like cilia, and from these cilia, the axons are sent into the olfactory bulb. The olfactory bulb is located in the forebrain which, in turn, projects to the pyriform cortex in the temporal lobe of the brain. Presumably more than 400,000 compounds are odorous to the human olfactory system. With the high number of compounds that are odorous to humans it is important to train panelist to detect the aromas that are key and that are being tested. It is easy, unlike gustation, for olfactory senses to have a contact time being too brief or having the detection area being overwhelmed for odor molecules to be detected thus it is important to sniff for 1-2 seconds and rest for 5 seconds before sniffing again to allow optimal detection (Meilgaard et al., 2007).

Beef Flavor

Beef flavor is a very complex topic that encompasses many different attributes and can be affected by countless factors. It is the most researched and studied meat flavor likely because of its status as the "king" of meat and its desirability. Beef flavor is a constantly developing factor that can be impacted from the time the animal is alive to the moment the sample is eaten. In many research projects it has been reported that differences in feed an animal is fed can affect the palatability and flavor of the meat. In one such study retail consumers rated steaks from grain-fed animals higher for overall flavor and palatability than grass-fed (Cox et al., 2006). This shows that the flavor of beef both comprises the composition of the raw meat, lean and fat portions, and the compounds developed through cooking, mainly the Maillard reaction and thermal lipid

degradation. Of these factors the major precursors to beef flavor are the water-soluble components and the lipids. The lipid portion contains species-specific flavors, whereas water-soluble compounds found in the lean portion contain the meaty/beefy flavor. The fluids containing the water-soluble compounds have a highly concentrated beef flavor upon cooking (Kramlich & Pearson, 1960). Hamburgers prepared from water-extracted ground beef were practically tasteless and odorless when sampled (Hornstein & Crowe, 1960). These studies indicated that the many components of beef flavor are found in the water-soluble portions of the meat. The components regarded as water-soluble are the amino acids, peptides, carbohydrates, nucleotides, thinines, sugars, nitrogenous compounds, and other similar compounds (Mottram, 1998).

Ongoing research through the years has further helped to identify the flavors present in beef and classify them as either desirable or an off-flavor. Much of the work has been done by using advances in technology, and comparing data from consumer sensory panels, expert trained sensory panels, and a gas chromatography (GC) and mass spectrometry (MS) with olfactory ports and correlating data to identify driving factors in consumer like. Miller and Kerth (2012) identified positive and negative beef flavors from the beef lexicon (Adhikari et al., 2011). With the development of the beef lexicon and the use of GC/MS to identify volatiles, positive beef flavors were identified. In the lexicon, positive beef flavors were identified as beefy, brown/roasted, bloody/serumy, fat-like, sweet, salty, and umami (Miller & Kerth, 2012). Attributes that were generally considered negative were metallic, liver-like, sour, barnyard, musty-earthy/humus and bitter. Beefy, browned/roasted, bloody/serumy, sweet, salty and umami were associated

with the lean portion of beef; while, fat-like, liver-like, metallic and bitter were associated with the lipid portion (Miller & Kerth, 2012). Roasts compared to steaks tended to have slightly higher levels of barnyard and musty-earthy/humus. When these flavors were combined with beefy, brown/roasted, and umami attributes, they may have developed into flavors consumers perceived as positive. Beef with a higher pH, oxidized beef fat, and high concentrations of myoglobin content may have caused liver-like, metallic and other off-flavors (Miller & Kerth, 2012)

Beef Flavor Development

Uncooked meat has little to no aroma with only a bloody/serumy taste (Mottram, 1998) and is a rich reservoir of compounds with taste tactile properties as well as aroma precursors and flavor enhancers (Bender & Ballance, 1961; Crocker, 1948). This is why cooking is very important in beef flavor and flavor development. Heating/cooking of beef is crucial in the development of the flavor of beef and results in a wide range of aroma volatiles being produced, the main reactions that occur during cooking that are responsible for flavor are the Maillard reaction and lipid thermal degradation (LTD). These reactions are what foster the flavor of the meat and transform it into the flavor consumers know and love. For these reactions to have any effect, heat must be present. Most importantly the flavors develop from the meat itself and flavor development is based on the meat composition. Meat is comprised mostly of water (75%), proteins (16-22%), lipids (1.5-13%), carbohydrates, vitamins, and minerals (Aberle, Forest, Gerrard, & Mills, 2001).

The main precursors to meat flavor are divided into two categories: water-soluble components and lipids (Mottram, 1998). From these two components aroma volatiles are formed during cooking. Over 1000 volatile compounds have been identified in meat. It is important to note that not all compounds are aromatic and contribute to the overall flavor of the meat.

Several hundred of these volatiles have been identified as coming from LTD. The production of these aromatic compounds are derived from the oxidation of the fatty acids found in the lipid portion of the muscle. Volatiles identified as coming from lipid degradation have been found to be aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acid and esters as well aromatics such as hydrocarbons (Mottram, 1998). The lipid in the muscle contains fatty acids, phospholipids, and triglycerides. The structural component of the cell membrane contains the lipid bilayer that is composed of phospholipids (Mottram, 1998). Phospholipids contain a much higher level of unsaturated fatty acids than the triglycerides (Mottram, 1998). Unsaturated fatty acids are more prone to oxidation because of the presence of double bonds when compared to saturated fatty acids (Mottram, 1998). Phospholipids are of vital importance during cooking as heat denaturation of the unsaturated fatty acids within the phospholipid result in development of volatile compounds that leads to development of positive and negative flavors.

The water-soluble components of beef flavor are: amino acids, carbohydrates, nucleotides, peptides, and nitrogenous compounds such as thiamine. The two main precursors to the water-soluble aromatic flavor compounds are cysteine and ribose.

Ribose is one of the main sugars present and is found in RNA and DNA. When these two components, cysteine and ribose, are combined under heat, a meat-like flavor is produced (Mottram, 1998). It has been shown that most of these changes occur because of the reactions between reducing sugars and amino acids in what is called the Maillard reaction. This reaction is why cooked meat, is beefy, and tastes good because of the reaction and the formation of pyrazines, which are associated with beef and roast flavor (Mottram, 1998). Raw meat is not beefy and contains low levels of flavor (Mottram, 1998).

Additionally, other components of the muscle contribute to flavor, such as myoglobin content, fatty acid content, lipid content, and non-heme iron content. Yancey et al. (2006) examined the effect of myoglobin concentration on the livery off-flavor in beef muscles. Other research demonstrated that the full effect of myoglobin content and meat pH on flavor attributes has not been fully clarified (Meisinger, James, & Calkins, 2006). Research by Glascock (2014) did not show strong correlations between myoglobin or non-heme iron content and liver-like, coinciding with findings from Meisinger et al. (2006).

Beef Species Flavor

Species flavor is primarily dependent on the lipid portion of an animal or cut of meat rather than the lean portion. Wasserman and Gray (1965) found that water extracted from lean beef, pork, and lamb developed a series of odors during boiling that possessed meat-like characteristics, but no species characteristics. In another study it was

also found that lean meat extracts of beef, pork, lamb, and even whale developed the same meaty aroma with no species characteristics (Hornstein & Crowe, 1960). This research reported that the meaty flavor and aroma came from the water-soluble portion, the lean portion, of the meat. This lead to hypothesizing that species-specific flavors come from the lipid or fat portion of the meat. Mottram (1998) conducted triangle tests using beef and pork lean and found that the inclusion of 10% fat, regardless of species origin, enabled taste panelists to distinguish lean type when compared to samples with no added fat. However when pork and beef fats were added to the same lean, differences were subtler, concluding that the lean contained some species-specific flavor and the addition of fat resulted in an interaction. Furthermore, fat-soluble volatile aromatic compounds and phospholipids (Melton, 1999) may also contribute to species-specific flavor. One of the major differences between the flavor of chicken broth and that of beef broth was the abundance of 2,4-decadienal, a major volatile present in the chicken broth. Two meaty flavor volatiles are 2-methyl-3-furanthiol and bis(2-methyl-3-furyl)disulfide that are found in beef broth samples and chicken broth samples (Melton, 1999). However, higher level of linoleic acid in chicken protect against oxidation of 2-methyl-3-furanthiol to bis(2-methyl-3-furyl)disulfide thus resulting in the decreased levels in the chicken broth.

Recent research indicates that the lean tissue in meat products may be the principal contributor to species-specific flavors (Myers et al., 2009). In mixed species samples, the predominant flavor was determined by the lean species. Increasing fat content in beef samples did not increase beef flavor, but decreased metallic/serumy

flavor. Additionally in the same study, it was found that fat in certain meat products played a role in species-specific flavors. As fat levels increased in pork, flavor increased. Acidic/sour flavor previously shown to be associated with pork (Myers et al., 2009) was not impacted by fat content. Acid/sour flavors were shown to be associated with light colored muscles such as the semimembranosus and semitendinosus of both beef and pork suggested that acid/sour flavors may be related to pH, as it has been found that light colored muscles have a lower pH (Myers et al., 2009). Myers et al. (2009) additionally found that darker colored muscles did not have any difference in flavor but fat content might influence differences.

Quality Grade

The primary means of determining the predicted palatability of a carcass is the determination of its quality grade. The quality grade measurement is a composite measurement and is said to relate to the likelihood of having a pleasurable eating experience, meaning having a steak that's tender, juicy, and flavorful (Miller, 1994). Beef carcass quality grading is based on two factors, degree of marbling and degree of maturity. Marbling is a measurement of the amount of intramuscular fat in the *Longisimus dorsi (LD)* between the 12^{th} and 13^{th} rib and is reported using a marbling score from practically devoid to abundant with 100° between each score (USDA, 1997). Maturity score is based on the animal's age and the final maturity score is based on a composition of lean and bone maturity. Maturity measurements are taken by measuring the ossification of the buttons of the dorsal spinous process of the thoracic vertebrae and

evaluating the color and texture of the lean. Maturity scores are reported using letter grades from A to E with A being the youngest. When the maturity score and marbling level have been determined, the carcasses are assigned one of eight USDA quality grades: Prime, Choice, Select, Standard, Commercial, Utility, Cutter and Canner (USDA, 1997).

Differences is quality grades have been found to impact the eating quality of a steak. In one study, Prime steaks were higher in flavor, juiciness, tenderness, and overall palatability than their lower-grading counter parts (Smith et al., 1987)**.** However other studies have found no differences in palatability when evaluating different steaks that differed in quality grades (Huffman, 1974; Parrish, Olson, Miner, & Rust, 1973). Marbling, which is a key determinant of quality grade, has a large impact on beef flavor. As the amount of marbling or intramuscular fat increases, the amount of fat flavor increases (Miller, 2001). In a study comparing slaughter plant location, USDA quality grade, external fat thickness, and aging time effects on sensory characteristics of beef loin strip steak, it was found that Choice steaks had higher flavor intensity ratings than the Select steaks (Miller et al., 1997). Berry and Leddy (1990) found that Small-marbled steaks had improved beef flavor and juiciness over Slight-marbled steaks, where Berry and Bigner (1995) noted no differences between Small- and Slight-marbled steaks

Differences in maturity also impacted the palatability of beef primarily via tenderness. One reason is that as the animal increases in age, the number of heat-stable collagen crosslinking increased resulting in increased toughness (Cross et al., 1973). It has been found that differences in steaks from A and B maturity carcasses was slight and

often unnoticed, but differences in steaks from A and E maturity levels was detectable and differed in palatability (Smith et al., 1982). Beef from older animals is more intense in flavor than younger animals and their meat is tougher due to the increase in insoluble collagen linkages (Miller, 1994). Additionally beef from older animals has lower palatability, tenderness, and flavor but increased levels of juiciness (Smith et al., 1982).

Steak Thickness

Thickness of steaks in retail and foodservice has been reported through the years by national surveys (Brooks et al., 2000; Guelker et al., 2013). Retail top loin steaks were found in the 2000 National Beef Tenderness Survey to be 2.39 ± 0.03 cm thick with food service steaks being cut thicker to 2.98 ± 0.04cm (Brooks et al., 2000). Additionally foodservice steaks were thicker than self-service retail steaks but the same thickness as full-service retail steaks and overall rib and loin steaks were cut thicker than steaks from other locations. Guelker et al. (2013) found similar results in that rib and loin steaks were again cut thicker and loin steaks were cut to 2.77 ± 0.05 cm and 2.91 ± 0.03 cm for retail and foodservice, respectfully. With all this research on what is available for sale and the tenderness impact, there is no current research on the impact of thickness on the sensory properties or consumer acceptance of beef steaks.

Cooking Temperature

Higher levels of intramuscular fat in beef steaks have permitted the use of higher temperature, rapid systems of cooking that also provide desirable palatability (Berry &

Bigner, 1995). Cooking methods that use higher temperature have led to development of new flavors and aromas in cooked steak that subsequently impact palatability. Most of the palatability differences have been attributed to the higher levels of fat in the steaks. In reality, a combination of the higher levels of fat as well as the higher temperature may have caused the development of desirable flavors. It was found in one of the few studies using different temperatures that steaks cooked in a oven at 232°C had lower ratings for flavor intensity than steaks cooked at 121°C; however, there was no difference in acceptability (Cross, Stanfield, & Koch, 1976). There has been very little research performed using different temperatures within one study or within one cooking method that has examined the subsequent effect on beef steak flavor.

Cooking Methods

There have been many studies using different cooking methods, but the use of different heat treatments within one cook system has not been extensively examined. Research has evaluated tenderness, but not flavor, with the cooking being done at one temperature and being cooked on clamshell grills or in ovens (Brooks et al., 2000; Guelker et al., 2013; Meisinger et al., 2006; Smith et al., 1982; Smith et al., 1987). It was noted by Lorenzen et al. (1999) that consumers had the highest likeability for flavor intensity when top Choice samples were cooked on an outdoor grill or panfryed. Additionally, consumers in Chicago rated steaks cooked using indoor grilling highest for palatability, while Houston consumers rated steaks lowest when they were cooked using indoor grilling. Consumer ratings of steaks cooked on the outdoor grill were lowest in

San Francisco while consumers in Chicago, Houston, and Philadelphia rated steaks highest that were outdoor grilled.

Kerth and Miller (2015) stated that the lower temperature associated with moist-heat cookery prevented beef steaks from reaching sufficient surface temperature for the development of Maillard reaction products (MRP). Additionally, use of lower temperatures inhibited the dehydration from the beef surface, the first step of the Maillard reaction. Some examples of moist heat cookery would be boiling and use of the crockpot especially with water. Also cooking with a lid on will have similar effects, as moisture from cooking cannot be removed in the cooking environment. Cooking using a clamshell grill would be an intermediate moist cooking method because during cooking moisture is maintained in the environment and steam is a component of the heat transfer mechanism for cooking. On the other hand, dry-heat cookery uses higher temperatures of >177°C. These temperatures result in dehydration of the meat surface that enabled the Maillard reaction and the color change to brown Kerth and Miller (2015).

Cooking Time and Temperature Relationship

While the thickness of steaks found in retail and foodservice has been previously reported (Brooks et al., 2000; Guelker et al., 2013), and some research has been done on cooking temperatures effect on palatability (Cross et al., 1976; Knize, Dolbeare, Carroll, Moore, & Felton, 1994; Skog, Steineck, Augustsson, & Jägerstad, 1995), research that examines these two factors and their subsequent effect on palatability has not been reported. Kerth et al. (2013) performed a study looking at differences in steak thickness

and grill temperature on cooking time, temperature and volatiles, but sensory work was not performed. This study looked at three differing steak thicknesses, 1.27 cm, 2.54 cm, and 3.81 cm, and three differing grill temperatures, 177°C, 204°C, and 232°C. It was found that steaks cut to the same thickness had the same cook time when cooked at different temperatures (Kerth et al., 2013). However, when steaks were compared by thickness to cooking time, steak thickness influenced cooking time and, as expected, the thicker steaks took longer and the thinnest steaks took less. Berry and Bigner (1995) found that beef loin steaks cooked at 232℃ had a faster cook time than steaks cooked at 204°C, but the same cook loss. Additionally, steaks cooked using 204° or 232°C surface cook temperature did not differ in connective tissue, tenderness, or beef flavor intensity. It is important to note that the cooking methods were slightly different than in the current study and steaks were cooked on a slated grill thus the temperature range varied more than the grill setting itself.

Kerth et al. (2013) took measurements of steaks during cooking, recording the steak surface temperature and the grill surface temperature during cooking. This is one of the first times these properties of a steak and grill have been measured and measured at the initial, flip, and final stages of cooking. As a steak cooks, water is lost from the steak primarily due to denaturation of the proteins. This water loss is important; as the water comes in contact with the grill or grilling surface, primarily a flat top, evaporative cooling occurs, lowering the surface of the cook top. Additionally, the water will also cause the surface of the steak to cool due to the same principle. Kerth et al. (2013) found that when the temperature was taken with an infrared thermometer, the skillet

temperature of all three treatments dropped by around 50°C from the initial surface temperature at the time of turning the steak. At the end of the cooking cycle when the steak had reached a defined internal cook temperature, the skillet surface temperature was 25-50°C lower than the temperature at the time of turning. The temperature of the cooking surface was higher at the time of turning for thicker steaks compared to thinner steaks. This was most likely due to the increased cooking time for thicker steaks that allowed the skillet to reheat. Thicker steaks had longer time to mid-cook turn than thin steaks. Additionally, the time required to cook after turning was up to 50% longer than the time required to reach the mid-point of cooking (defined as the turning point or when the steak reached the internal temperature that was half of the final internal cook temperature endpoint). During cooking of the steak first side, it was hypothesized that water accumulated on the top of the steak. When the steak was turned half way through the cooking process, this water most likely cooled the cook surface. Though a previous study found that the steak surface measured with a non-contact, infrared thermometer never reached above 100°C during cooking (Kerth et al., 2013); however, most research stated that temperatures must get above 120-150°C for MRP to form (Shahidi, 1998).

Maillard Reaction

Browning occurs in many foodstuffs consumed everyday. Browning develops during cooking or storage, and is associated with food positive and negative flavors, visual appeal, and quality (Shahidi, Samaranayaka, & Pegg, 2004). Browning occurs due to two main types of mechanisms, enzymatic and non-enzymatic. While conceptually it

is easy to differentiate between the two, in reality the division is very vague and difficult to pinpoint one mechanism or another. Under certain conditions it is easy to rule out one mechanism or another. During heat processing enzymes would be inactivated (Shahidi, 1998) indicating that browning is due to non-enzymatic browning. The Maillard reaction and caramelization are the two types of non-enzymatic browning that occur in foodstuff**.** In beef steak cooking, the Maillard reaction is the main reaction (Shahidi, 1998) and the one of concern here.

The reaction is very wide spread in food products and ubiquitous occurring mainly during processing at elevated temperatures and prolonged storage. By-products of the Maillard reaction contribute to the flavors and colors of many foodstuffs such as coffee, chocolate and meat (Shahidi et al., 2004). The reaction produces many nutritional and toxicological changes in food, even playing a role in the humic substances in soil and water leading to brown colors. The reaction is made up of seven reactions steps (Nursten, 2005) that are divided into three stages: initial, intermediate, and final (Hodge, 1953) or early, advanced, and final (Mauron, 1981). The classic diagram provided by (Hodge, 1953) still provides the basis for understanding non-enzymatic browning and the Maillard reaction. The initial stage, where there is no color development, is comprised of two reactions: reaction A - sugar-amine condensation; and reaction B - Amadori rearrangement (Nursten, 2005). The intermediate stage in which product is still colorless or might have a yellow tint is comprised of three reactions: reaction C - sugar dehydration; reaction D - sugar fragmentation; and probably the most important reaction in regards to flavor reaction E - Strecker degradation. The final stage in which product

color mainly develops contains two reactions: reaction F - aldol condensation; and reaction G - aldehyde-amine condensation.

The Maillard reaction is very complex and has been extensively studied (Mottram, 1998). The Maillard reaction occurs between amino acids and reducing sugars (Shahidi et al., 2004). Amine compounds condense with the carbonyl group of a reducing sugar in the presence of heat (Calkins & Hodgen, 2007). The first step of the reaction is dehydration in which glucosamine is rearranged and dehydrated forming furfural, furanone, hydroxyketone, and dicarbonyl compounds (Hodgen, 2006). As the reaction progresses, the glucosamine is rearranged into 1-amino-1-deoxy-2-ketose which can form two isomers that allow the continuation of the Maillard reaction as illustrated in the classic diagram by (Hodge, 1953). At the end of the intermediate stage, Strecker degradation begins. This step is probably the most important reaction in regards to flavor and of most interest to flavor chemistry. Strecker degradation is the degradation and breakdown of amino acids and dicarbonyl compounds and the transformation of these compounds into aldehydes (Shahidi, 1998). The aldehyde that is formed, called a Strecker aldehyde, contains one less carbon atom than the original amino acid. Carbon dioxide also is formed (Shahidi et al., 2004). For the amino acids to become aldehydes, they are decarboxylated and de-animated while the dicarbonyls become α-aminoketones and amino-alcohols (Shahidi, 1998). The aldehydes then condense to form aldols that form furans, pyrazines, pyrolles, oxazoles, thiazoles, and other hetrocyclic compounds that are odor molecules.

If the amino acid that goes through Strecker degradation is cysteine the reaction produces ammonia, hydrogen sulfide and acetylaldehyde; all three of which are very important in the formation of different classes of flavor compounds in cooked meats (Shahidi et al., 2004). These compounds form pungent aromas that are generated during cooking (Mottram, 1998). Most importantly, sulfur compounds that are derived from cysteine and ribose are key in the generation of aromatic characteristics of cooked meats (Shahidi et al., 2004). These compounds have been shown to be the most important compounds in meat flavor (Shahidi, 1998).

Most flavor compounds generated via the Maillard reaction are N-, S-, and O-heterocycles and other sulfur containing compounds that give cooked meat a meaty, boiled, and roasted aroma (Shahidi et al., 2004). These compounds are derived primarily from the peptide backbone that yields nitrogen. The side chains of amino acids that yield sulfur and C, H, and O from lipids (Kerth & Miller, 2015) have been shown to lead to the compounds that are large contributors to the overall aroma profile of cooked meat (Shahidi et al., 2004). The main classes of flavor compounds contributing to aroma in cooked meat are furans (containing O), pyrazines (containing N), pyrroles (containing N), oxazoles (containing N), thiophenes (containing S), thiazoles (containing S) and other heterocyclic compounds (Kerth & Miller, 2015).

Oxygen-Containing Compounds

Oxygen containing compounds do not contribute to a high degree to the final aroma in beef, but they are more important as an intermediate compounds and contribute

to the formation of other N- and S-containing meat flavor volatiles (Shahidi et al., 2004). The main O-containing compounds are furans and pyrans, for example furfural. These compounds usually originate from sugars and produce caramel-like aromas in cooked meats.

Nitrogen-Containing Compounds

Pyrazines and pyrroles are the main N-containing compounds in meat products with oxazoles and oxazolines compounds minor contributors to meat flavor. Oxaoles and oxazolines have green or vegetable-like aroma that are found in meat, but other sulfur containing compounds produce similar aromas with closely related chemical structures and tend to be more significant contributors to meat flavor (Shahidi et al., 2004). Pyrazines are major contributors to meat flavor and have been extensively examined, for example, pyrazines accounted for 77% of the total volatiles in well-done grilled pork (Shahidi et al., 2004). Pyrazine formation was very dependent on moisture content, temperature, and duration of cooking. Pyzazines have been proposed to be formed by α-dicarbonyl compounds formed during Strecker degradation (Shahidi et al., 2004). The increased level of three Maillard products, 2,3-dimethyl-pyrazine, 2,5-dimethyl-pyrazine, and trimethyl-pyrazine, have been shown to be positively affected by increased time and temperature during cooking (Kerth & Miller, 2015). Different forms of pyrazines have been found to have nutty and roasted aromas in cooked meats and are vital to the roasted flavor in high-temperature cooked meat. There have been 48 pyrazines found in beef compared to the 16 from lamb and 36 from pork (Shahidi et al.,

2004). Kerth et al. (2013) were able to manipulate the amount of pyrazines in beef steaks through cooking surface temperature and steak thickness. They also found that as the temperature of the cooking surface increased, the amount of pyrazines increased.

Sulfur-Containing Compounds

The last fundamental group, sulfur-containing compounds, has been shown to be the most important volatile formed during meat cookery (Shahidi, 1998). Most of the sulfur-containing compounds occur at very low concentration, but these compounds have very low odor thresholds (Shahidi et al., 2004). As a result, a small level of sulfur-containing compounds is easily detectable by humans. The primary precursor to these compounds is hydrogen sulfide, which is produced mainly through the Strecker reaction hydrolysis by cysteine. Thiophenes have been indicated as the most important flavor compound from the Maillard reaction. Thiophenes produce meaty aromas in cooked meat (Shahidi et al., 2004). Of the thiophene and furan groups the most important are compounds with sulfur or methyl groups on the first, second, or fifth position of the ring that results in a highly desirable meaty aroma. Additionally, when a thiol is on the third position of the furan or thiophene ring, a very low threshold meaty aroma was produced (Shahidi et al., 2004). Thaizoles and thiazolines are dependent on the nature and number of alkyl moieties attached to the compound, but many have been found to have roasted and meaty characteristics (Shahidi et al., 2004). Increased levels of thiazoles and thiazolines are found by cooking beef with higher temperature cooking (Shahidi et al., 2004). Polysulfur heterocyclics, which have a meaty aroma, comprise 65 of the 78

compounds described to have a meaty aroma by and again are very dependent on the temperature as well as the acidity for development (Shahidi et al., 2004).

Lipid Thermal Degradation

Lipid thermal degradation is the breakdown of polar phospholipids and neutral triglycerides with heat (Kerth & Miller, 2015). The polar lipids are more easily broken down with heat due to their higher levels of unsaturation and the absence of one fatty acid on the glycerol carbon (Kerth & Miller, 2015). When unsaturated phospholipids are degraded, they produce many volatiles that are important to flavor.

Volatiles from lipid thermal degradation (LTD) have been identified as aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acid and esters as well aromatics such as hydrocarbons (Mottram, 1998). The formation of these compounds result from the oxidation of the fatty acid components of lipids. In cooked meats these reactions occur rapidly and lead to many positive flavor attributes. In meats in long-term storage, these reactions happen more slowly and lead to rancid off-flavors defined as lipid oxidation. The LTD volatiles are quantitatively dominant in meat flavor development unless high heat cooking methods are used that result in extensive browning where the majority of aromatic volatiles would be derived from the Maillard reaction (Kerth & Miller, 2015). The LTD products have high thresholds for human detection (Kerth & Miller, 2015). In meat the lipid content is usually higher than other protein sources (Kerth & Miller, 2015) and so LTD products have been shown to be major contributors to cooked meat flavor.

Maillard Reaction and Lipid Thermal Degradation Interaction

The interaction between products of LTD and MRP has been reported (Kerth & Miller, 2015; Mottram, 1998; Shahidi, 1998; Shahidi et al., 2004)**.** The multiple products from LTD and MRP have been shown to form both aromatic and non-aromatic compounds and it is inevitable they would interact as they are contained in the same system. Interactions of LTD and MRP form new compounds, limit development of some compounds and inhibit formation of other compounds (Kerth & Miller, 2015). These interaction compounds are derived from lipid oxidation, yielding aliphatic aldehydes that form alkyl groups and the Maillard reaction giving amino acids the source of nitrogen and sulfur (Shahidi, 1998). The compounds formed are O-, N-, or S-heterocyclic containing long *n*-alkyl substituents. The interactions form heterocyclic compounds such as pyrazines, pyradines, and thiazoles with long chain alkyl substituents. While some of these compounds are similar to those developed through the Maillard and lipid thermodegration pathways, the quantity of volatile compounds produced from the interaction reactions are thought to be low (Shahidi, 1998)**.** The by-products of the interaction of MRP and LTD have not been extensively examined as these products have a very high odor thresholds that results in very low human odor intensity (Kerth & Miller, 2015). In other words, there must be very high levels of the compounds for them to be detected by humans. However the interaction reactions do inhibit or limit Maillard reaction production of heterocyclic aroma compounds. As they inhibit production of Maillard reaction products, these interactions may lead to positive flavors from otherwise undesirable compounds. The formation of these positive flavors

via the interaction is also thought to be the case in sulfur-containing compounds, which in high levels can produce off-flavors and undesirable traits (Kerth & Miller, 2015). But with the production of the sulfur containing compounds limited it occurs in very desirable levels and is one of the most important flavor producing compounds.

Fatty Acids

Fatty acid levels in meat have been shown to affect meat firmness, shelf life, and flavor (Wood et al., 2004). Fatty acids impact meat flavor through the release of volatiles during lipid oxidation. Lipid oxidation occurs during cooking and storage. During cooking, fatty acids rapidly oxidize or autoxidize and interact with Maillard reaction products to form volatiles that contribute to the odor and flavor of the meat (Wood et al., 2004). During storage, this lipid oxidation leads to rancid and off-flavors. It is important to note that the type of fatty acids, unsaturated, polyunsaturated, and saturated, also affects the rate of oxidation (Wood et al., 2004). Unsaturated fatty acids go through autoxidation at a faster rate than saturated fatty acids (Mottram, 1998). The capability of unsaturated fatty acids, primarily those with multiple double bonds, to rapidly oxidize, is important in regulating the shelf life of meat (Wood et al., 2004). Alternatively, this inclination to oxidize is important in flavor development during cooking.

Palmitoleic (16:1), oleic (cis 9), linoleic (18:2, cis 9) and linolenic (18:3) are the predominant unsaturated fatty acids found in beef and 18:2, cis 9 is the most abundant fatty acid in the animal body (Wood et al., 2004). While the saturated fatty acids of palmitic acid (16:0) and stearic acid (18:0) are present in higher levels, lauric acid

(12:0), myristic acid (14:0), or arachidonic acid (20:4) are present in small quantities (Wood et al., 2004).

Mandell, Buchanan-Smith, and Campbell (1998) found that beef fat aroma, a very desirable attribute to consumers, was positively correlated with increased levels of 14:0, 16:0, and 18:1 and negatively correlated with fatty acids containing grassy and metallic flavors. Metallic was negatively correlated with 18:1 and positively correlated with 18:3. They concluded that increased levels of 18:1, oleic acid, increased desirability. Additionally, greasy, an attribute similar to fat, was also positively correlated with oleic acid. Melton, Black, Davis, and Backus (1982) found that cooked beef fat was positively correlated to 14:1, 16:1, 17:1, and 18:1 levels while sour taste was negatively correlated to 18:1. Additionally, cooked beef fat flavor was negatively correlated with levels of 18:0, 18:3, 15:0, 19:1, 20:1, and 20:4 (Melton et al., 1982). Melton et al. (1982) found that ground beef with the most desirable flavor had increased levels of 18:1 neutral lipids with lower concentrations of 18:0 and 18:3 neutral and polar lipids.

Gas Chromatography with Mass Spectrometry

Volatiles have been analyzed for nearly half a century to determine what chemical compounds are present and to measure their amounts (Shahidi, 1998). The gas chromatograph (GC) is able to separate volatiles into compounds and the mass spectrometer (MS) system is able to identify these compounds. To use the system to evaluate volatile compounds, volatiles are collected using a solid phase microextraction

(SPME) in the headspace of a container. The volatile compounds are collected on the SPME and injected into the GC/MS where they are transported through the column via a carrier gas, helium. In the GC, the samples are separated based on their volatility while traveling through the column; compounds with higher volatility will be transported faster than ones with low volatility. The system is capable of detecting hundreds of thousand of compounds. Within one sample, there will hundreds of volatiles that it will detect, however, not all of these volatiles will be aromatic (Shahidi, 1998). To only identify the aromatic compounds, olfactory ports have been added to the GC (GC-O) to allow separation and detection of aromatic producing volatiles. Human "sniffers", usually trained panelists, will then sniff the samples from of the olfactory ports denoting on the system when they detect an aroma. The samples are transported from the GC column through the MS where they are identified and mixed with humidified air and out the port for the panelist. As a panelist detects an aroma, an aromagraph is generated in conjunction with a chromatograph enabling the identification of the compound that produced aromas. There may be only a small fraction, in the range of 10-50 compounds of the hundreds of measured volatiles that actually impact aroma and flavor of foods (Mottram, 1998).

The GC-O technology can also be used to identify the different odor thresholds of flavor compounds (Shahidi, 1998). Individual compounds have different odor thresholds and humans detect volatile aromatic compounds at different concentrations. Aromas can occur at very low concentration and have sensory relevance due to low threshold values. During cooking, lipids are thermally degraded giving various

derivative compounds that are aromatic, but these compounds traditionally have much higher aroma thresholds (higher concentrations are required to detect an aroma) compared to MRP (Mottram, 1998). While many of the peaks are very small and small changes are seen, it is important to remember that because many of the MRP have extremely low odor detection thresholds, even small changes in type and quantity are very important (Kerth & Miller, 2015). Volatile aromatic chemicals and thresholds can be correlated to overall consumer liking, This information can be used to give specific cutting and cookery instructions to generate maximum volatile aromatic compounds that match consumer liking (Kerth et al., 2013).

CHAPTER III

MATERIALS AND METHODS

Meat

Beef strip loins (IMPS 180) from 32 random animals were selected on two selection trips from Kane Beef (Corpus Christi, TX). USDA Select (n = 16) and upper two-thirds USDA Choice (n = 16) carcasses were selected after grading by a USDA grader and grading by Texas A&M Meat Science personnel trained in grading to confirm USDA Quality grade (USDA, 1997). Vacuum-packaged strip loins were transported to Texas A&M University Rosenthal Meat Science and Technology Center and stored at 4°C for 14 d. Because steak thickness was a primary treatment, the strip loins were placed in the freezer after aging to allow uniform and precise cutting of the steaks on a band saw. Strip loins were frozen at -40°C for a minimum of 24h and held at -40°C until slicing on the band saw. After intact strip loins were frozen, one strip loin from each animal was divided into 12 portions for 2 cooking temps (high temperature = 232°C or low temperature = 177°C) x 2 steak thicknesses (thin steaks = 1.3 cm and thick steaks = 3.8 cm) so that three steaks per subclass (temperature x steak thickness) was obtained per strip loin. Steaks were trimmed to 0.25 cm external fat. The difference in thickness was selected to allow extremes in the amount of cooking time that would be required to reach the desired internal temperature allowing for maximum and minimal Maillard reaction products. Quality grade differences were selected to affect the level of umami, fat-like, and metallic flavor attributes. Steaks were labeled and vacuum-packaged

individually (B2470, Cryovac Sealed Air Corporation, Duncan, SC) with an oxygen transmission rate of 3-6 cc at 4°C (m^2, 24 hrs atm @ 4°C, 0% RH) and a water vapor transmission rate of 0.5-0.6 g at 38°C (100% RH, 0.6 m^2, 24 h). Once packaged, steaks were boxed, and placed into frozen storage at -23°C for up to 7 mo until analyses were performed. For each analysis, individual steaks were selected and thawed in refrigerated (4°C) storage for 12 to 24 h. Steaks for all cooked analyses were placed on the grill, turned when the internal temperature reached 37°C and removed when the internal temperature reached 71°C (medium degree of doneness) to allow optimal cooking time on both side of the steak for Maillard reaction products development. Steaks were cooked on a 2.54 cm thick flat top Star Max 536TGF 36 in (91.44 cm) Countertop Electric Griddle with Snap Action Thermostatic Controls (Star International Holdings Inc. Company, St. Louis, MO) set at either 177°C or 232°C. Internal temperatures were monitored by iron-constantan thermocouples (Omega Engineering, Stanford, CT) inserted into the steak geometric center. Surface temperatures of the grilled steak surface [flip (midpoint), final] and the grill surface in the location where the steak was placed [initial, flip (midpoint), final] were taken with iron-constantan surface probe (Model 88402E, Omega Engineering, Stanford, CT). These measurements were used to determine the way the grill and steak surface temperature change during cooking due to the evaporative cooling caused by water loss of the steak during the cooking process. Temperatures were displayed using an Omega HH501BT Type T thermometer (Omega Engineering, Stanford, CT).

This design resulted in four flavor treatments within a carcass with a total of 8 treatments between Quality grades (2 steak thickness x 2 grill temperatures x 2 Quality grades). Each treatment within a cut and carcass were prepared for expert, trained descriptive attribute flavor evaluation in College Station, TX; consumer sensory evaluation in State College PA, Portland OR, Griffin GA and Olathe KS; cooked chemical flavor volatile analysis; and raw chemical fat/moisture, pH, non-heme iron, myoglobin, and fatty acid analyses.

Expert, Trained Descriptive Beef Flavor Analyses

Steaks were evaluated by a 5-member, expert trained beef flavor descriptive attribute panel that helped develop and validate the beef lexicon (Adhikari et al., 2011) and that were used in the previous study with light and moderate to heavy beef eaters (Glascock, 2014). This panel was retrained using the beef lexicon for 14 d. Beef flavor attributes were measured using the beef lexicon (0 = none and 15 = extremely intense) defined in Table 2. After training was complete, panelists were presented 12 samples per day, divided into two sessions. Prior to the start of each trained panel evaluation day, panelists were calibrated using one orientation or "warm up" sample that was evaluated and discussed orally. After evaluation of the orientation sample, panelists were served the first sample of the session and asked to individually rate the sample for each beef flavor lexicon attribute. Double distilled water, unsalted saltine crackers, and fat-free ricotta cheese were available for cleansing the palette between samples. After cooking, samples were stored at 60°C for < 20 min until being served. When panelists were ready

samples were cut into 1.27 cm cubes. Two cubes per sample were served in clear, plastic soufflé cups tested to assure that they did not impart flavors on the samples. Samples were identified with random three-digit codes and served in random order. Samples were cut and served immediately to assure samples were approximately 37°C upon time of serving. During evaluation, panelists were seated in individual breadbox-style booths separated from the preparation area and samples were evaluated under red lights. In order to prevent taste fatigue, each evaluation day was divided into two sessions, with a ten-minute break between sessions and samples were served four minutes apart.

Consumer Evaluation

Consumers (n = 80 per city) were randomly selected in four cities (Olathe, KS; State College, PA; Griffin, GA; and Portland, OR) so that geographical areas represented the Midwest, the east coast, southeast and the west coast. In each city, four consumer sessions with approximately 20 consumers per session were conducted. After completion of each consumer session, four to five consumers (n = 20 consumers per city) were asked to participate in one-on-one interviews to determine attitudes toward beef and beef flavor.

Consumer panelists were recruited by the individual research intuition and all panelists were required to pass a consumer screener guaranteeing them to be over 20 y of age, have no food allergies, and consume beef (including ground beef). On the day of evaluation, recruited consumer panelists were asked to sign an informed consent document. An instructional document, demographic ballot and eight individual sample

ballots were provided to the consumers upon entering the testing room. Consumer demographics for age, sex, income, household income, type of employment, dietary restrictions, protein sources consumed, meat consumption levels of beef, meat shopping habits, cook surface temperature preference, steak thickness preferance, beef types and flavor types were determined (Consumer Form 1). The ballot included overall, overall flavor, beefy flavor, grilled flavor, juiciness and tenderness liking using 9-point hedonic scales (Consumer Form 2). Two open-ended questions were asked to describe any positive or good flavors and any negative or bad flavors within each sample were included on the ballot. Panelists were provided 8 pre-identified random samples in a pre-determined random order four minutes apart. Samples were served in clear, plastic soufflé cups, as previously defined, labeled with a random three-digit number corresponding to their ballot. Samples were cut and prepared as defined for expert, trained beef flavor descriptive analysis

Cooked Beef Volatile Flavor Evaluation

Volatiles were captured from the same steaks evaluated by the consumer panelists in State College, PA. After samples were prepared for consumers, approximately 75g of 1.25 cm beef cubes were placed in foil with a tag separated from the meat samples. Samples were placed in liquid nitrogen and frozen to -196°C. Samples were stored at -80°C until volatile analysis. Volatiles were evaluated using the Aroma Trax gas chromatograph/mass spectrophotometer system with dual sniff ports for characterization of aromatics (MicroAnalytics-Aromatrax, Round Rock, TX). This

technology provided the opportunity to separate individual volatile compounds, identify their chemical structure and characterize the aroma/flavor associated with the compound. Samples were placed in heated glass jars (473 mL) with a Teflon lid under the metal screw-top to avoid off-aromas and then set in a water bath at 60°C and thawed for 1h. Then the headspace was collected with a Solid-Phase Micro-Extraction (SPME) Portable Field Sampler (Supelco 504831, 75 µm carboxen/ polydimethylsiloxane, Sigma-Aldrich, St. Louis, MO). The headspace above each meat sample in the glass jar was collected for 2 h. The SPME was then injected in the injection port of the GC where the sample was desorbed at 280°C. The sample was then loaded onto the multi-dimensional gas chromatograph into the first column (30m X 0.53mm ID/ BPX5 (5% Phenyl Polysilphenylene-siloxane) X 0.5 µm, SGE Analytical Sciences, Austin, TX) that separated compounds based on boiling point. Through the first column, the temperature started at 40°C and increased at a rate of 7°C/minute until reaching 260°C. Upon passing through the first column, compounds were sent to the second column [(30m X 0.53mm ID; BP20- Polyethylene Glycol) X 0.50 µm, SGE Analytical Sciences, Austin, TX] that separated compounds due to polarity. The gas chromatography column then split into three different columns at a three-way valve with one going to the mass spectrometer (Agilient Technologies 5975 Series MSD, Santa Clara, CA) and two going to the two humidified sniff ports with glass nose pieces heated to 115°C. The sniff ports and software for determining flavor and aroma were part of the AromaTrax program (MicroAnalytics-Aromatrax, Round Rock, TX). Panelists were trained to accurately use the Aromatrax software after they had been trained according to the beef lexicon aromas.

Raw Chemical Analyses

Raw meat pH, fatty acid composition, myoglobin content, and non-heme iron content were determined from each raw muscle within carcass. The pH was determined in duplicate (pH meter calibrated daily with 4.0 and 7.0 pH buffer solutions; IQ Scientific Instrument, Model IQ150, IQ Scientific Instrument, Inc., Carlsbad, CA,) by inserting the probe in two random locations within the anterior face of each subprimal.

Fatty acid methyl esters (FAME) were prepared from the lipid extracts as described by Morrison and Smith (1964). Approximately 3-5 g of ground beef was combined with 1 mL of 0.5 KOH in MeOH and heated at 70°C for 10 min. After cooling, 1 mL of Boron trifluoride (BF3 (14%, wt/vol) was added to each sample, which was flushed with N_2, loosely capped, and heated at 70°C for 30 min. The samples were removed from the bath, allowed to cool to room temperature, and 2 mL of HPLC grade hexane and 2 mL of saturated NaCl were added to the samples and the samples were vortexed. After phase separation, the upper phase was transferred to a tube containing 800 mg of Na_2SO_4 to remove moisture from the sample. An additional 2 mL of hexane was added to the tube with the saturated NaCl and the samples were vortexed again. The upper layer was transferred into the tube containing the Na_2SO_4. The hexane extract was transferred to glass scintillation vials. The sample was evaporated to dryness at 60°C under N_2 gas, subsequently reconstituted with HPLC grade hexane, and analyzed using a Varian gas chromatograph (model CP-3800 fixed with a CP-8200 auto- sampler, Varian Inc., Walnut Creek, CA; Chung et al., 2006). Separation of FAME was accomplished on a fused silica capillary column CP-Sil88 [100 m x 0.25 mm (i.d.)] (Chrompack Inc.,

Middleburg, Netherlands) with helium as the carrier gas (flow rate = 1.2 mL/min). After 32 min at 180°C, oven temperature increased at 20°C/min to 225°C and was held for 13.75 min. Total run time was 48 minutes. Injector and detector temperatures were at 270°C and 300°C, respectively. Standards from Nu-Check Prep, Inc. (Elysian, MN) were used for identification of individual FAME. Individual FAME were quantified as a percentage of total FAME analyzed. All fatty acids normally occurring in beef lean and fat trim, including isomers of conjugated linoleic acid, were identified by this procedure.

Myoglobin concentration was conducted according to Ricksand and Henrickson (1967) with modification to be read using a 96-well plate reader. Duplicate 25g samples were blended with 100 mL of DDH_20 for 3 min and centrifuged at 2000 x *g* at 6°C for 15 min. The supernatant was filtered through Whatman No. 3 filter paper and brought to volume in a 200 mL volumetric flask. From this 200 mL portion, duplicate 5 mL portions were taken and adjusted to pH of 7.1 using 0.5M phosphate buffer. Then 1.25 mL of saturated lead acetate was added to the tube and centrifuged at 2000 x *g* for 15 min. Then, 2.5 mL of the supernatant was combined with a mixture of mono- and dibasic phosphate to bring the phosphate concentration to 3M and the pH to 6.6. The sample was again centrifuged at 2000 x *g* for 15 min. The 1 mL of the supernatant was combined with 0.7 mL of potassium ferricyanie and 0.7 mL of potassium cyanide to convert all forms of myoglobin to cyanmetmyoglobin. The samples were again centrifuged at 2000 x *g* for 15 min to ensure that all myoglobin had been transformed. Then 200 µL was pipetted in triplicate on a 96 well plate and read at 520 nm. The concentration of myoglobin was then calculated from the formula: myoglobin

concentration (mg/g wet tissue) = (OD x K) / (sample wt.). The proportionality constant (K) was calculated from the formula K = (17,000 X vol. of aliquot in liters X dilution factor)/E (Rickansrud & Henrickson, 1967).

For non-heme iron, samples were prepared following the procedures described by Rhee and Ziprin (1987) and read at 533 nm using a Epoch UV/Visual Spectrophotometer (BioTek,Winooski, VT). To determine total non-heme iron, final absorbance of each sample was calculated by subtracting the absorbance of the incubated liquid phase with no color reagent added from the absorbance of the incubated liquid phase with color reagent added. Next, final concentration was calculated by subtracting the intercept of the standard curve from the final absorbance and dividing by the slope of the standard curve. Finally, non-heme iron was calculated as follows:
ug non-heme Fe/g meat = concentration (ug/mL) x (15 + 0.2 + moisture in 5g meat)/5g x 1 mL

Statistical Analyses

The trained panel descriptive flavor attributes and the volatile compounds were analyzed using least squared means in JMP (version 11, SAS Institute, Cary, NC) to understand what chemical attributes drive specific beef flavor attributes. A predetermined alpha of ($P < 0.05$) was used in all analyses. For stepwise regression analysis, dependent variables were defined as overall consumer liking and trained descriptive attributes of beef identity, brown/roasted, bloody/serumy, metallic, liver-like and umami. Independent variables were volatile compounds defined using the Aroma

Trax and were allowed to enter the equation ($P \leq 0.05$). Final equations were presented and the intercept ß values and partial r^2 for each independent variable and final equation for r^2 were presented. For analysis of variance of chemical data, the data were analyzed as a completely random design with steak thickness, cooked surface temperature and Quality grade as main effects. Two- and three- way interactions of main effects were included in the model. For trained panel data, data were averaged across panelists and sensory day and order served were defined as random variables. For consumer data, city, steak thickness, cooked surface temperature, Quality grade and their interactions were included as main effects and order served was defined as a random variable. For volatile category data, steak thickness, cooked surface temperature, Quality grade and their interactions were included as main effects. Least squares means were calculated and the pdiff function of SAS was used to determine differences between least squares means when significance was defined in the analysis of variance. Multivariate analysis was conducted using XLSTAT (Addinsoft, New York, NY) where principal component and partial least squares regression functions were used. Data were presented in bi-plots.

CHAPTER IV

RESULTS AND DISCUSSION

Consumer Demographics

The demographics of the consumers (n = 310) are reported in Table 1. Nearly 66% of the consumers were between 26 and 55 years old with ages ranging from 18 to 66 or older. There were slightly more females than males in the study, and around 55% of consumers came from two- to three-person-size households. Consumers had a balance of income levels and about 60% of the consumers had full time jobs. As expected, consumers mainly consumed beef, pork, chicken, and fish either at home or in a restaurant. Beef was eaten 1 to 2 times a week by 47.9% of consumers which was less than the 75.2% of consumers who ate pork 1 to 2 times a week and 73.4% who ate fish 1 to 2 times a week, but similar to the 48.5% who ate chicken 3 to 4 times a week. Lamb and soy based products were seldom consumed by consumers. Of the beef purchased, consumers mainly purchased traditional beef at the retail store with a select few preferring grass fed and even fewer preferring organic. Outdoor grilling was the preferred method of cooking a beef steak with the grill set at either 350°F or 400°F by most of the consumers. The majority of consumers preferred beef steaks cooked to either medium, medium rare, or medium well visual degrees of doneness.

These demographics were very similar to Glascock (2014) and Luckemeyer (2015) as expected as three of the four cities were the same for the three studies. Glascock (2014) had slightly more females than males across a wide range of ages and

salaries with consumers eating a wide range of proteins multiple times a week. Glascock (2014) and Luckemeyer concluded that consumer demographics were representative of beef consumers and were acceptable demographics to address effects of treatments on beef consumer acceptability.

Over half of the consumers preferred purchasing a steak that was cut to a thickness of 2.54 cm. The National Beef Tenderness Survey (Brooks et al., 2000) found that the average top loin steak was 2.98 cm thick, slightly thicker than what was indicated by consumers in this study as their perceived preferred thickness. The following National Beef Tenderness Survey (Guelker et al., 2013) found that top loin steaks had gotten slightly thinner being on average 2.77 cm thick. This thickness was more in line with consumer desired thickness for this study.

Expert Trained Descriptive Flavor Panel Attributes

Trained panel sensory testing was performed using flavor attributes from the beef flavor lexicon (Adhikari et al, 2011; Table 2). To determine if treatments affected beef flavor attributes, least square means for beef flavor attributes across treatments were reported in Table 3. No three-way interactions were present for flavor attributes. Thickness by temperature interaction was not significant ($P > 0.05$) for bloody/serumy, liver-like, and smokey charcoal flavor attributes. No previous research has been found comparing the effect of steak thickness on bloody/serumy flavor. However, when comparing means the thinner steak had a higher ($P > 0.05$) bloody/serumy. As steaks across thickness were cooked to the same internal temperature, thinner steaks had shorter

cook times that would have limited heat denaturation of myoglobin, one of the factors contributing to bloody/serumy flavor. Luckemeyer (2015) and Glascock (2014) found that as internal cook temperature increased, bloody/serumy decreased.

Steaks highest in beef identity ($P < 0.05$) were the 3.8 cm (3.8) steaks cooked at the lower 177˚C (177) temperature, and lowest ratings ($P < 0.05$) were in the 1.3 cm (1.3), 177 steaks. Brown/roasted flavor scores were highest ($P < 0.05$) in the 3.8 steaks cooked at either temperature, but lowest ($P < 0.05$) in the 1.3 steaks cooked at 177.

Additionally, the 1.3 steaks from either Quality grade were rated lower ($P < 0.05$) in brown/roasted flavor aromatics than the 3.8 cm (3.8) steaks, but the Choice 3.8 steaks were rated the highest ($P < 0.05$) in brown/roasted compared to all other treatments. Bloody/serumy scores were higher ($P < 0.05$) in the 1.3 than 3.8 steaks and in 177 than 232˚C (232) temperature steaks. The thicker steak at a higher temperature had lower ($P < 0.05$) fat-like, sweet, and overall sweet attributes, but higher ($P < 0.05$) metallic, bitter, and burnt when compared to steaks from the other treatments.

Sour basic taste was the highest ($P < 0.05$) and salty basic taste was lowest ($P < 0.05$) in the thinnest steaks cooked at the lowest temperature. Steaks that were 3.8 thick had the highest ($P < 0.05$) salty basic taste. Liver-like, having very low intensity ratings was highest ($P < 0.05$) in the thinnest Choice steaks.

Temperature by Quality grade interaction was significant ($P < 0.05$) for salty basic taste. Choice top loin steaks cooked at 232 were high ($P > 0.05$) in salty basic taste. Bloody/serumy and liver-like flavor aromatics were higher in top loin steaks

cooked at 177 and smokey charcoal flavor aromatic was higher in steaks cooked at the 232 grill temperature and in 3.8 thick steaks.

Choice steaks were higher in fat-like and overall sweet flavor aromatics, and umami and sweet basic tastes and Select steaks were higher in metallic mouthfeel and sour basic tastes. Thinner steaks were higher ($P < 0.05$) in muscle fiber tenderness and overall tenderness. Differences in other treatments were not reported for juiciness, muscle fiber tenderness, connective tissue amount, and overall tenderness.

Top loin steaks that were thicker and cooked using the lower surface cook temperature that had the most positive ($P < 0.05$) flavor attributes of beef identity, browned/roasted, bloody/serumy, fat-like flavor aromatics, and sweet, salt, and umami basic tastes. Miller and Kerth (2012) showed that the aforementioned flavor and basic taste attributes were positive attributes for consumers. On the other hand the thicker steaks cooked at the higher temperature ranked the highest in three negative flavors and a basic tastes, metallic, bitter, smokey, and charcoal burnt. These attributes were, in some cases, more than double reported in steaks from the other treatment, leading to very strong undesirable flavors.

Contradictory to Cross et al. (1976), in which it was found that temperature did not affect flavor when roasting in an oven, it was found that temperature was a major factor in the development and differences in flavor of beef top loin steaks. Temperature played a major role eliciting differences ($P < 0.05$) in 10 of the 14 flavor attributes that were present in the samples. Cross et al. (1976) used a more indirect cooking method where heat was not in direct contact with the meat. It can by hypothesized that making

contact with the heated surface during beef cooking will have a greater impact on the flavor development in the meat because on the direct heat transfer and the ability of heat to impact either Maillard or lipid thermal denaturation reactions that have been shown to contribute to cooked meat flavor.

Consumer Perception of Beef Flavor

Consumers evaluated beef top loin steaks from the same treatments used for expert trained panel (Table 4). Quality grade by steak thickness and Quality grade by cook surface temperature did not impact consumer sensory ratings ($P > 0.05$). Choice top loin steaks were higher in grilled flavor liking when compared to Select top loin steaks ($P < 0.05$). These results are similar to Legako et al. (2015) who found that Select and Top Choice strip steaks cut to 2.5 cm and cooked on a clamshell grill at 225˚C for 5 min did not differ in juiciness, flavor liking, or overall liking. Oppositely Hunt et al. (2014) cooked and prepared steaks similarly to the previous study but found differences in all consumer attributes. Hunt et al. (2014) reported that consumers ranked Top Choice steaks higher. Smith et al. (1987) found that broiled Choice top loin steaks were rated higher in flavor, juiciness, and overall palatability than Select top loin steaks when evaluated using a trained meat descriptive attribute sensory panel. However Luchak et al. (1998) reported that Choice and Select top loin steaks did not differ in trained meat descriptive attributes of juiciness and flavor intensity. Luchak et al. (1998) additionally found that cooking method affected the sensory properties for eye of round steaks. Eye of round steaks were either pan broiled at 163˚C or braised by searing at 121˚C and then

cooked in water at 163˚C. Pan broiled eye of round steaks were higher for all trained meat descriptive sensory attributes but mainly for juiciness and flavor intensity.

Cook temperature by steak thickness interactions were significant ($P < 0.05$; Table 4) for the highest number of attributes, and thus, were the primary driver of differences between treatments. Thick steaks grilled at 232 had the lowest ($P < 0.05$) consumer ratings for juiciness, overall flavor, beef flavor, grill flavor, and overall liking. Overall and overall flavor liking were similar ($P > 0.05$) for the remaining treatments. Consumers rated the beef flavor highest ($P < 0.05$) for thicker steaks cooked at 177. However, 3.8 steaks cooked at 177 and 1.3 steaks cooked at 232 were rated highest ($P < 0.05$) for grilled flavor liking. Steaks cooked at the lower grill temperature had higher ($P < 0.05$) juiciness liking. Overall, the study found temperature and thickness to have the greatest impact on consumer liking.

Berry and Bigner (1995) examined palatability of steaks cooked using two cooking methods at two temperatures within each cooking method. While palatability differences were not extensive, steaks cooked on a slated grill at either 204˚C or 232˚C did not differ in beef flavor intensity or juiciness. These results differed from the results of the current study. In the current study, steaks were cooked using a flat top grill where the actual cooking surface was either 177 or 232. Berry and Bigner (1995) used a slated grill that sat 1.2 cm above the heat source and actual cook surface temperatures were between 74˚C and 99˚C. This temperature difference most likely affected steak flavor development, mainly in the rate of the Maillard reaction. The Maillard reaction requires high heat (>130°C-140°C) for the reaction to occur rapidly during the cooking process.

However the reaction can also occur at room temperature over time (Shahidi et al., 2004). Ultimately the temperatures at which the reaction occurs are highly debated and there is not one consensus of a temperature range.

Raw Chemical Attributes

Chemical attributes were determined on raw steaks prior to cooking and are reported in Table 5. Choice top loin steaks had lower ($P < 0.05$) levels of non-heme iron and myoglobin compared to Select top loin steaks. Inversely, Choice top loin steaks had a higher ($P < 0.05$) percentage of lipid and lower percentage of moisture than Select steaks, as expected.

Both polar and neutral oleic acid (18:1; Table 6) were higher ($P < 0.05$) in Choice steaks. Additionally, neutral linoleic acid (18:2) was higher ($P < 0.05$) in Select steaks as compared to Choice steaks. No other polar or neutral fatty acids were affected by Quality grade in top loin steaks ($P > 0.05$). Major fatty acids, 16:0, 18:0, 18:1, 18:2, 18:3, and 20:4, were reported at similar levels to previous research with the exception of 18:2 levels in top loin steaks. Slightly elevated levels were observed from values reported in previous research (Enser et al., 1998).

Volatile Aromatic Flavor Components

Table 7 defines the volatile aromatic compounds reported by the GC/MS system. The mean area under the curve for each compound is reported. There were 218 volatile aroma compounds defined. In previous research, Luckemeyer (2015) found 248 volatile

aromatic compounds. Luckemeyer (2015) used multiple muscles and cooking methods that would expectantly result in a higher number of volatile aromatic compounds. In another study, Glascock (2014) reported 149 volatile aromatic compounds. While Glascock (2014) also had multiple cuts, cook temperature was lower than in the present study. Analysis of the aromatic compounds showed ketones to be the most abundant type of volatile. Forty-two ketone volatile aromatic compounds were reported indicating that ketones were a key component in beef flavor. There were 38 volatile aromatic aldehydes reported. The remaining types of volatiles were, in decreasing order were: alkanes (30), alcohols (26), pyrazines (23), furan (14), acids (13), benzenes (9), sulfur-containing (8), other (6), pyrrol (5), nitrogen-containing (1), pyridine (1), pyrimidine (1), and pyran (1).

Volatile aroma compounds of the top loin steaks were categorized by volatile chemical type into 9 categories in order to understand the effects of steak thickness, cook surface temperature and quality grade on volatile aroma flavor compound levels (Table 8).

Thicker steaks had higher ($P < 0.05$) levels of alkanes and acids, primarily derived from LTD, and higher ($P < 0.05$) levels of pyrazines, furans, and sulfur-containing compound; were mostly derived from the Maillard reaction. Additionally, thicker steaks had higher ($P < 0.05$) levels of aldehydes derived from both reactions and their interaction. As thicker steaks had longer ($P < 0.05$) cook times, they were exposed to heat for a longer time providing an opportunity for more Maillard reaction and LTD

products to form. However, thinner steaks had more alcohol compounds ($P < 0.05$). Steak thickness did not affect the level of ketones and benzenes compounds ($P > 0.05$).

Cook surface temperature did not affect ($P < 0.05$) the level of ketones and aldehydes. Steaks cooked using the higher temperature had more pyrazines, furans, sulfur-containing, and benzene compounds; whereas top loin steaks cooked using the lower cook surface temperature contained more alkanes and alcohols ($P < 0.05$). Cook surface temperature did not affect the level of volatile aromatic acids in top loin steaks ($P > 0.05$). For individual volatile aromatic compounds, thicker steaks cooked using a higher surface temperature had higher ($P < 0.05$) levels of hexanal, a green, fatty, or unpleasant aroma, and 2,3-octanedione. These compounds have been associated with lipid oxidation (St. Angelo et al., 1987).

Aldehydes, which are derived from both MR and LTD as well as their interaction, were major volatile contributors. Some key compounds such as 2-hexenal commonly associated with green apple and bitter aromas; acetaldehyde with fresh and green; (e)-2-decenal with mushroom and earthy aromas; hexanal with green and grassy aromas; octenal with citrus-like and green; pentenal is associated with winey, fermented and bready; phenyl acetaldehyde with sweet; and honey, waxy, buttery are in undecanal. These compounds 2-hexenal ($P < 0.05$), hexanal, octenal, pentanal ($P < 0.05$), and phenyl acetaldehyde were all significant ($P < 0.01$) for the temperature treatment at 177. However in the 232 temperature treatment, the compounds (e)-2-decenal and undecanal were significantly higher ($P < 0.01$). Additionally acetaldehyde and pentanal were

significantly higher for the 1.3 ($P < 0.01$) and 3.8 ($P < 0.05$) thickness treatments, respectively.

Ketones are produced from both afore mentioned flavor reactions. Three key chemicals significantly higher at the 177 treatment were 2-propaneone ($P < 0.05$), described as pungent, 2,3 octanedione ($P < 0.01$), and 1-octen-3-one ($P < 0.05$), which associated with mushroom. The latter was also significantly higher ($P < 0.05$) in the 3.8 treatment. 2-nonanone, which is associated with cheesy, green, and bittery, was significant ($P < 0.01$) at 232.

For the thickness treatment, trimethyl-pyrazine was higher ($P < 0.05$) in 3.8 steaks compared to the 1.3. Additionally for the temperature treatments, trimethyl-pyrazine, as well as 2-ethyl-5-methyl-pyrazine, and 3-ethyl-2,5-dimethyl-pyrazine were higher ($P < 0.05$) for the 232 steaks. The latter two pyrazines are associated with peanut, caramel, popcorn and coffee aromas. Trimethyl-pyrazine is considered to have a raw, musty and potato like aromas. All three of these compounds are likely to come from the MR. Lastly, 2-pentyl-furan, also likely a MR product, is associated with green, caramel and methanethiol, a sulfur containing compound, is linked with vegetable oil, eggy and creamy. Both of these compounds were significantly higher ($P < 0.01$) in the 3.8 treatment than the 1.3 treatment.

In order to understand how consumer attributes influenced overall consumer like/dislike, the stepwise linear regression equation including only consumer variables to predict overall consumer like/dislike are reported in Tables 9, 10, and 11. Overall like consisted of 18 chemical compounds, flavor like 15 chemical compounds, and beef

flavor 16 chemical compounds, they accounted for 22.66%, 15.43%, and 14.79% of the variation in overall consumer like/dislike, respectively.

Stepwise Linear Regression for Volatile Flavor Attributes

Stepwise linear regression equations to predict trained panel beef descriptive flavor attributes are presented in Tables 13 to 19. Regression equations for beef flavor identity, brown/roasted, bloody/serumy, fat-like, metallic, liver, and umami flavor attributes were calculated, as these were the major descriptive flavor attributes that varied. These equations accounted ($P < 0.05$) for beef flavor identity (51%), brown/roasted (55%), bloody/serumy (30%), fat-like (35%), metallic (53%), liver (87%), and umami (24%) beef flavor descriptive attributes variability. These aromatic chemical attributes can be used to predict beef flavor attributes. While it is not practical to measure each of these attributes for every piece of beef cooked or served, examination of treatments or conditions that affect or increase aromatic compounds related to beef identity, browned/roasted, bloody/serumy, fat-like and umami would increase consumer acceptance

Trained Descriptive Flavor Panel and Cook Data Correlation

Correlation coefficients were also calculated for trained sensory panel data (Table 20) comparing the major flavor attributes beef flavor identity, brown/roasted, bloody/serumy, fat-like, metallic, liver, and umami to the cooking parameters of grill temperature (initial, flip, final), steak surface temperature (flipping, final), grill time (1st

side, 2nd side, total) and percent cook loss. Both beef flavor identity and brown/roasted were moderately correlated ($P < 0.05$) to grill time on the first side and total grill time. This suggests that as the amount of grill time increases more time is given for the development of Maillard reaction products allowing more for the development of these flavors. Additionally final steak surface temperature had a low correlation ($P < 0.05$) for beef flavor identity and brown roasted. Metallic was the only other attribute that had a positive correlation ($P < 0.05$) of interest having a low correlation to the overall grill time and first and second side grill times. Bloody/serumy, fat-like, and livery all had negative correlations to all of the cooking parameters with bloody/serumy being having a moderately negative correlation ($P < 0.05$) for initial grill temperature, final steak surface temperature, and final grill temperature. These trends stated above also transit to the cooking loss percentage, as the cook loss increased beef flavor identity, brown/roasted, and metallic increased while bloody/serumy, fat-like, livery, and umami decreased.

Cooking Surface And Steak Temperatures

Steak thickness. Steak thickness and its effect on grill temperature variations (Figure 1) was averaged across the two temperature treatments for the different thicknesses and as expected there was no difference ($P > 0.05$) between thicknesses for either the grill or steak initial surface temperature. Similarly the flip grill surface was not different ($P > 0.05$) for either treatment. This was different than Kerth et al. (2013) in which there was a difference between the grill temperature across the three thickness

treatments with the 3.8 cm having a much higher grill temperature. The possible reason for the difference in this current study was likely the grill, which was designed to hold and react to temperature changes via thermostatic controls. The results of significance were the flip steak surface, final steak surface and final grill surface; all three were higher in the 3.8 cm steak. The steak surface was logically higher because they spent more time on the grill and had been dehydrated more on the surface due to the increased time thus limiting the subsequent evaporative cooling. Similarly the grill temperature was likely higher because since they were on the grill longer thus the grill had a longer time to recover from the initial evaporative cooling and return as close as it could to its initial temperature.

Grill temperature. Figure 2 represents the grill temperatures effect on the grill surface and steak surface, sensibly throughout 232 had a higher ($P < 0.05$) grill surface temperature than 177. After cooking on the first side grill temperatures for both treatments decreased ($P < 0.05$) by on average 21.15°C, interestingly though, at the flip, 232 had decreased ($P < 0.05$) by 12.3° more, comparatively, than the 177 treatment. For cooking on the second side grill temperature decreased ($P < 0.05$) again by an average of 3.85°C and the 177 deceased by 4.5° more, comparatively, than the 232 treatment. This suggests that the grill and steak might reach equilibrium between the amount of evaporative cooling and the rate the grill can reheat. Supposedly it would additionally be dependent on the grill itself with results varying with different type grills. Following the same trend the 232 treatment had a higher ($P < 0.05$) overall steak surface temperature at both the flip and final readings, the values were also slightly higher for the final than

they were for the flip, these results are consistent with (Kerth et al., 2013). Differing from their research it was found that in this study temperatures for the steak surface were consistently above 100°C being around 200° to 225°C whereas they found the steak surface never reached above 100°C. This is important because it is commonly known in the field of flavor chemistry that you need high temperature for Maillard reaction products to form, one possible reason for the difference in the temperature is that they used a non-contact thermometer whereas this study used a contact thermometer.

Cooking time. Cooking time was measured for the steaks and is illustrated in Figures 3 and 4, steaks cooked at a lower temperature took a longer ($P < 0.05$) time to cook on side two and overall. Thinner steaks also took a shorter time ($P < 0.05$) than the thicker steaks to be cooked on both sides and overall. Kerth et al. (2013) found near identical results showing that thicker steaks all cooked longer and lower temperature grill required more time to cook. One difference is that they found the second side took significantly longer to cook than the first side and the current study found that the time was almost similar for both side of the steak again this is probably due to the cooking method whereas they used cast iron skillets and we used thermostatic commercial grill.

Partial Least Square Regression Biplots

A partial least square regression biplot of consumer sensory panel attributes, trained sensory panel attributes, and treatments was performed to analyze clustering and grouping of the attributes. It was found that many attributes clustered together and showed what previous data had illustrated, both steaks that were cut thick and cooked at

the higher temperature were closest to bitter, burnt, and smokey charcoal, all three of which were tightly clustered. This would be expected as these are all negative attributes and were found as illustrated in Table 3 to be found in higher levels in these steaks and would be expected as was seen during the cooking process as these steaks cooked at a high temperature for longer time have charring and significant crust formation.

The consumer attributes beef flavor liking, flavor liking, juiciness liking, and overall liking all closely clustered together. This was also seen by previous research (Glascock, 2014; Luckemeyer, 2015), they also both found that fat-like was very highly correlated with overall liking. This was also true in this study with fat-like being closely grouped with overall like but also similar were sweet and overall sweet. The four thin steaks with the exception of the Choice steak cooked at the higher temperature were all the closest grouped with liver-like, sour, and bloody/serumy however both of the thinner steaks cooked at a lower temperature were the closest grouped with the attributes.

Both of the thick cut Choice steaks were the treatments most closely related to brown roasted and beef identity. These two attributes were very closely grouped showing their strong relation to each other, this was also found by Glascock (2014). Glascock (2014) found though that these attributes were very closely related to umami and bitter, which were almost on top of each other, a main difference though was that bitter and burnt were not clustered in her findings. Looking at the overall view, while the attributes were closely clustered within one quadrant, in this present study not as many attributes were identified causing more weight to be placed on the ones found, pulling them apart more. The attributes, brown/roasted, beef ID, bitter, burnt, salty, umami, and

grill flavor, albeit not closely grouped as was found by Glascock (2014) and Luckemeyer (2015) they are the attributes most closely related to each other and show relation to each other, the treatments and relation to consumer like.

Looking again at the thick-cut Choice steak cooked at the higher temperature was pulled opposite from overall like whereas the lower temperature steak was pulled close to overall like while being clustered with salty and umami and the closest treatment to grilled flavor liking. This supports the data that the Choice 3.81 177 steak was the overall favorite of the consumers as it was very close to many positive flavor attributes such as umami, fat-like, overall sweet, brown roasted, and beef identity but far from negative attributes such as bitter, burnt, sour, and liver-like. Additionally, Glascock (2014) found that their Choice top loin steaks grilled to 60˚C was the treatment most closely related to umami, beef identity, brown/roasted and other similar attributes as found in this current study.

Consumer sensory panel attributes, trained sensory panel attributes, and treatments were used with the addition of volatile flavor compounds were analyzed in a partial least squares regression biplot in Figure 6. This biplot was of much interest because in previous research Glascock (2014) and Luckemeyer (2015) the volatile attributes closely grouped near the center of the biplot and did not cluster around specific attributes. However, in this current study the volatiles did not closely cluster around the center but spread out across the biplot and clustered around attributes.

Again the Choice 3.81, 177 steak was most closely located to grill flavor liking, umami, salty, beef ID, brown/roasted and similarly close as the same treatment but

Select quality grade to overall consumer like. These all fall in the upper left quadrant and there can be observed distinct groups of clustering. Most of the consumer attributes cluster together including: beef flavor liking, flavor liking, juiciness liking and overall liking. Of keen interest is that within this cluster of consumer liking we find the descriptive attributes overall sweet and fat-liking. As previously found by (Glascock, 2014; Luckemeyer, 2015) and as discussed by (Kerth & Miller, 2015). Fat-like has been found to be a driver for consumer like as well as very closely related to the overall like and flavor. Similarly they also found that overall sweet was closely grouped with overall like and might possibly be an additional driver for consumer like. Interestingly in this current study the one volatile compound of the 71, used in the biplot, phenyl acetaldehyde, which has been described as having a sweet aroma was the only compound in the cluster with consumer likings (Kerth & Miller, 2015).

Grill flavor, umami, and salty tended to cluster and had around eight or nine other compounds clustered close to this grouping. The treatment that was most closely associated with the cluster was the Choice 3.81 177. The compounds in this cluster include (and aromas generated), 2-octenal (green, nutty, fat; Calkins & Hodgen, 2007), 2,3-octanedione (green apple, bitter; Kerth & Miller, 2015) and 2-pentyl-furan (green been, butter). Moving right towards salty the compounds start to group tighter with 2-hexanal, and 1-octen-3-ol (mushroom). These compounds, being almost on top of each other, will likely still contribute largely to umami and grill flavor while having more of and impact on the salty attribute. Consequently, salty and umami are similar flavors, as umami is described as, being a mix of savory and salty, and having a synergistic effect

making that flavor all more powerful (Shahidi, 1998). Interestingly 1-octen-3-one was also present and has a mushroom aroma. This means that two of the compounds have a mushroom aroma and four have a green aroma suggesting that they play a large role in either grilled flavor, salty, umami, or all three. These compounds in this cluster are mostly formed from likely LTD with some aldehydes and the furan possibly being formed due to Maillard reaction.

The other cluster on the biplot that stands out with a distinct grouping around it is in the bottom right around sour and the Select 1.27 177 treatment. There are multiple volatile compounds, likely deriving from LTD, making a circle around them. The only neighboring flavor attributes liver-like, which is closely grouped with chavicol and the Choice 1.27 177 treatment, and bloody/serumy, which has no distinct volatiles nearby. Both 2-propanone (pungent), and octane are stacked on top of each other and fall directly on the Select 1.27, 177 treatment. Other volatile compounds nearby such as acetaldehyde, which has a green aroma (Kerth & Miller, 2015) has in other research been found to group around these similar compounds such as dimethyl sulfide and be in the same area as overall like and other consumer sensory attributes (Legako et al., 2015). In review, this quadrant contained three of four 1.27 cm steaks and the fourth was barely outside with them tending to have more liver-like, sour, bloody/serumy attributes and a majority of the volatiles being derived from likely LTD.

Beef identity, brown/roasted, smokey charcoal, bitter, burnt, and metallic are the remaining attributes which are all found on the right side of the biplot along with both of the thicker treatments cooked at the higher temperature. These two treatments being

cooked at such a high temperature and for such a long period of time resulted in a large amount of browning and charring on the surface of the steak and likely lots of Maillard reaction products. This is thought to be because when high heat dry cookery methods are used Maillard reaction products are formed (Mottram, 1998). Additionally looking at the biplot it can be seen that a large number of the compounds clustered around the thicker steaks cooked at a higher temperature and the attributes smokey charcoal, bitter, and burnt are pyrazines and furrans, both derived primarily from the Maillard reaction.

CHAPTER V

CONCLUSIONS

The combination of steak thickness and grill temperature greatly influenced differences in both flavor development and volatile compound formation. Given the extremes used to create flavor differences, consumers tended to like thicker cut steaks cooked at a lower temperature but 3.8 steaks cooked at 232 were disliked by consumers the most, likely because of their strong relationship to the burnt, smokey charcoal, and bitter beef attributes. The 3.8 steaks cooked at 177 were closely related to many positive beef flavor attributes such as overall sweet, fat-like, umami, salty, beef identity, brown roasted, and sweet while negative attributes such as metallic, sour, liver-like, bitter, burnt, and smokey charcoal were not as closely related. These steaks cut at 3.8 and grilled at 232 had the lowest acceptance for overall liking, overall flavor liking, beef flavor liking, grill flavor liking, and juiciness. Quality grade did not play a part in the flavor attributes of the steaks with the exception of grill flavor liking in Top Choice steaks.

Volatiles were found to differ between treatments and were able to be clustered with different attributes showing distinct groupings. For the thickness treatments alkanes and acids, which are derived primarily from LTD, were all more present in 3.8 steaks. Additionally pyrazines, furans, and sulfur-containing compounds produced primarily during Maillard reaction as well as aldehydes, which are derived from both reactions and their interaction were all more present in 3.8 steaks. This is likely due to the more time

they needed for cooking because of their thickness thus, resulting in more Maillard reaction products and LTD products being able to form. The steaks prepared at 232 had higher presence of pyrazines, furans, sulfur-containing, and benzenes. Whereas the 177 treatment had predominately alkanes, alcohols, and acid compounds. The grouping of the compounds was ideal in this study, and it was easy to identify key groupings of volatiles that correlated with flavor attributes such as phenyl acetaldehyde being the closest related to the grouping of consumer likings. Overall, the study found that temperature and thickness had the greatest impact on the steaks.

Ultimately, this research could be used to improve the overall flavor of beef presented to consumers by utilizing thickness and temperature to maximize the development of positive beef flavors and minimize negative beef flavors. Steaks could be cut thicker and cooked at a lower temperature long enough for the development of positive Maillard reaction products while also preventing overcooking at high temperature to limit the development of negative beef attributes such as burnt and bitter. It was found that the thicker cut of the steaks promoted these positive flavor developments while the thinner cuts, despite still being liked by consumers, have more off-flavors associated.

The identification of aromatic volatiles that drive consumer liking and aromas associated with different attributes is an important step that needs more work in the study of the flavor chemistry. By identifying these compounds and when they are formed we will have the ability to be able to better predict, and improve beef flavor,

especially during cooking, and utilizing preparation and cooking methodology to maximize the positive flavors.

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APPENDIX A

TABLES

Table 1. Demographic frequencies for beef consumers (n = 310) across four cities.

Question	Number of Respondents	Percentage of Respondents
Sex		
Male	141	45.5
Female	169	54.5
Household size including yourself		
1	44	14.0
2	106	33.8
3	69	22.0
4	61	19.4
5	21	6.7
6 or more	13	4.1
Age		
20 years or younger	18	5.7
21 - 25 years	41	13.1
26 - 35 years	67	21.3
36 - 45 years	71	22.6
46 - 55 years	63	20.0
56 - 65 years	51	16.2
66 years and older	2	1.0
Household income		
Below $25,000	76	24.4
$25,001 - $49,999	73	23.4
$50,000 - $74,999	59	18.9
$75,000 - $99,999	45	14.4
$100,000 or more	58	18.6
Employment level		
Not employed	66	21.0
Part-time	60	19.1
Full-time	188	59.9

Table 1. (con't) Demographic frequencies for beef consumers (n = 310) across four cities.

Question	Number of Respondents		Percentage of Respondents	
Proteins consumed at home or at a restaurant (away from home)				
At Home	**Do not Consume**	**Consume**	**Do not Consume**	**Consume**
Chicken	6	305	1.9	98.1
Beef	11	300	3.5	96.5
Pork	31	280	10.0	90.0
Fish	52	259	16.7	83.3
Lamb	238	73	76.5	23.5
Eggs	10	301	3.2	96.8
Soy Based Products	199	112	64.0	36.0
Away from Home /Restaurant	**Do not Consume**	**Consume**	**Do not Consume**	**Consume**
Chicken	11	299	3.5	96.5
Beef	8	302	2.6	97.4
Pork	44	266	14.2	85.8
Fish	44	266	14.2	85.8
Lamb	189	121	61.0	39.0
Eggs	30	280	9.7	90.3
Soy Based Products	205	105	66.1	33.9
Weekly consumption of protein				
Beef				
0	2		0.6	
1-2	149		47.9	
3-4	123		39.6	
5-6	25		8.4	
7 or more	12		3.9	
Pork				
0	27		8.9	
1-2	228		75.2	
3-4	35		11.6	
5-6	10		3.3	
7 or more	3		1.0	
Lamb				
0	205		65.3	
1-2	49		15.6	
3-4	5		1.6	
5-6	1		0.3	
7 or more	0		0.0	

Table 1. (con't) Demographic frequencies for beef consumers (n = 310) across four cities.

Question	Number of Respondents	Percentage of Respondents
Chicken		
0	2	0.7
1-2	95	31.1
3-4	148	48.5
5-6	47	15.4
7 or more	13	4.3
Fish		
0	38	13.0
1-2	215	73.4
3-4	33	11.3
5-6	4	1.4
7 or more	3	1.0
Soy Based Products		
0	137	54.8
1-2	84	33.6
3-4	21	8.4
5-6	7	2.8
7 or more	1	0.4

What cooking method do you prefer to use when cooking a beef steak?

	Do not use	**Use**	**Do not use**	**Use**
Pan-frying or using a skillet on the stove	152	159	48.9	51.1
Stir Fry	205	106	65.9	34.1
Grilling Outside	44	267	14.1	85.9
Oven Broiling	224	87	72.0	28.0
Oven Baking	215	96	69.1	30.9
Microwave	301	10	96.8	3.2
Electric Appliance (George Foreman Grill) or other electric grill	251	60	80.7	19.3

Degree of doneness preference

Rare	10	3.2
Medium Rare	90	28.6
Medium	96	30.6
Medium Well	77	24.5
Well	27	8.6
Very Well	11	3.5

Table 1. (con't) Demographic frequencies for beef consumers (n = 310) across four cities.

Question	Number of Respondents	Percentage of Respondents
At what temperature do you typically set the cook surface (grill, pan, oven, etc.)?		
Lower than 177C	10	3.2
232C	118	37.6
204C	118	37.6
232C	38	12.1
Higher than 232C	20	6.5
When purchasing beef, what thickness do you prefer to buy at the retail store?		
Less than 1.30 cm	13	4.1
1.30 cm	70	22.3
2.54 cm	185	58.9
3.80 cm	41	13.1
Thicker than 3.80 cm	5	1.6
When purchasing beef, what do you typically tend to buy at the retail store?		
Grass Fed	69	22.1
Dry Aged	13	4.2
Organic	38	12.2
Traditional beef at the retail store	237	76.0

What flavor or types of cuisines do you like?

	Do not Eat	**Eat**	**Do not eat**	**Eat**
American	20	292	6.4	93.6
Barbeque	19	293	6.1	93.9
Mexican/Spanish	25	287	8.0	92.0
Indian	191	121	61.2	38.8
Chinese	30	282	9.6	90.4
Greek	155	157	49.7	50.3
Japanese	140	172	44.9	55.1
Italian	74	298	19.9	80.1
French	187	125	59.9	40.1
Thai	146	166	46.8	53.2
Lebanese	235	77	75.3	24.7

Table 2. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where [1]0 = none; 15 = extremely intense from Adhikari et al. (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Animal hair	The aromatics perceived when raw wool is saturate with water.	Caproic acid (hexanoic acid) = 12.0
Beef identity	Amount of beef flavor identity in the sample.	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Bloody/serumy	The aromatics associated with blood on cooked meat products. Closely related to metallic aromatic.	USDA choice strip steak = 5.5 Beef brisket = 6.0
Brown/roasted	A round, full aromatic generally associated with beef suet that has been broiled.	Beef suet = 8.0 80% lean ground beef = 10.0
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat Puffs = 5.0
Chemical	The aromatics associated with garden hose, hot Teflon pan, plastic packaging and petroleum based product such as charcoal liter fluid.	Zip-Loc sandwich bag = 13.0 Clorox in water = 6.5
Cocoa	The aromatics associated with cocoa beans and powdered cocoa And chocolate bars. Brown, sweet, dusty, often bitter aromatics.	Hershey's cocoa powder in water = 3.0 Hershey's chocolate kiss = 8.5 (flavor)

Table 2. (con't)

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Cooked milk	A combination of sweet, brown flavor notes and aromatics associated with heated milk.	Mini Babybel original Swiss cheese = 2.5 Dillon's whole milk = 4.5
Dairy	The aromatics associated with products made from cow's milk, such as cream, milk, sour cream or butter milk.	Dillon's reduced fat milk (2%) = 8.0
Fat-like	The aromatics associated with cooked animal fat.	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Green	Sharp, slightly pungent aromatics associated with green/plant/vegetable matters such as parsley, spinach, pea pod, fresh cut grass, etc	Hexanal in propylene glycol (5,000 ppm) = 6.5 (aroma) Fresh parsley water = 9.0
Green-hay	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley and tea leaves	Dry parsley in medium snifter = 5.0 (aroma) Dry parsley in ~30-mL cup = 6.0
Leather	Musty, old leather (like old book bindings)	2,3,4-Trimethoxybenzaldehyde = 3.0 (aroma)
Liver-like	The aromatics associated with cooked organ meat/liver	Beef liver = 7.5 Braunschweiger liver sausage = 10.0 (must taste and swallow)

Table 2. (con't)

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Overall sweet	A combination of sweet taste and sweet aromatics. The aromatics associated with the impression of sweet.	Post-shredded wheat spoon size = 1.5 Hillshire farms Lit'l beef smokies = 3.0 SAFC ethyl maltol 99% = 4.5 (aroma)
Rancid	The aromatics commonly associated with oxidized fat and oils. These aromatics may include cardboard, painty, varnish and fishy.	Microwaved Wesson vegetable oil (3 min at high) = 7.0 Microwaved Wesson vegetable oil (5 min at high) = 9.0
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Sour aromatics	The aromatics associated with sour substances.	Dillon's buttermilk = 5.0
Sour dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing cow light Swiss cheese = 7.0 Dillon's buttermilk = 9.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Spoiled	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in propylene glycol 10,000 ppm) = 12.0 (aroma)

Table 2. (con't)

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% accent flavor enhancer solution = 7.5
Warmed-over	A product that has been previously cooked and reheated.	80% lean ground beef (reheated) = 6.0
Other attributes Smoky – charcoal, smoky – wood, buttery, refrigerator-stale, soapy, barnyard, heated oil, asparagus, cumin, floral, beet and petroleum-like		

Table 3. Beef flavor attributes[1] least squares means for USDA Select and Top Choice beef top loin steaks across grill temperature and steak thickness

Treatment	Beef identity	Brown/ roasted	Bloody/ serumy	Fat-like	Liver- Metallic	Liver- like	Umami	Basic Taste Sweet	Basic Taste Sour	Basic Taste Salty	Basic Taste Bitter	Overall Sweet	Burnt	Smokey Charcoal
P > F														
Thickness	0.001	0.001	0.001	0.057	0.009	0.23	0.31	0.001	0.001	0.63	0.001	0.008	0.001	0.001
Grill Temp.	0.13	0.001	0.001	0.07	0.51	0.06	0.004	0.001	0.004	0.94	0.001	0.01	0.001	0.02
Quality Grade	0.056	0.022	0.68	0.001	0.018	0.60	0.001	0.013	0.001	0.17	0.69	0.001	0.90	0.30
Thick x Temp.	0.001	0.001	0.53	0.001	0.015	0.20	0.001	0.003	0.045	0.004	0.001	0.003	0.001	0.15
Thick x QG	0.20	0.032	0.17	0.19	0.62	0.035	0.17	0.82	0.93	0.25	0.51	0.55	0.68	0.64
Temp x QG	0.51	0.87	0.44	0.44	0.80	0.13	0.37	0.54	0.52	0.04	0.76	0.66	0.99	0.78
Thickness (cm) x Temperature °C														
1.3, 177	5.9^{d}	1.0^{c}	1.4	1.0^{a}	2.1^{b}	0.06	0.5^{bc}	0.4^{a}	2.0^{a}	1.4^{c}	1.7^{b}	0.6^{a}	0.1^{b}	0.0
1.3, 232	6.4^{c}	1.9^{b}	0.8	1.2^{a}	2.0^{b}	0.01	0.5^{b}	0.4^{a}	1.7^{b}	1.6^{ab}	1.8^{b}	0.6^{a}	0.5^{b}	0.1
3.8, 177	6.8^{a}	2.3^{a}	1.0	1.2^{a}	2.1^{b}	0.02	0.8^{a}	0.4^{a}	1.7^{b}	1.6^{a}	1.9^{b}	0.6^{a}	0.6^{b}	0.1
3.8, 232	6.6^{b}	2.1^{a}	0.6	0.8^{b}	2.3^{a}	0.01	0.3^{c}	0.1^{b}	1.7^{b}	1.5^{bc}	3.4^{a}	0.3^{b}	3.5^{a}	0.4
Thickness (cm) x Quality Grade														
1.3, T. Choice	6.2	1.4^{c}	1.2	1.2	2.0	0.05^{a}	0.6	0.5	1.8	1.5	1.7	0.7	0.3	0.0
1.3, Select	6.1	1.4^{c}	1.1	1.0	2.1	0.02^{ab}	0.4	0.3	2.0	1.5	1.8	0.5	0.3	0.0
3.8, T. Choice	6.8	2.4^{a}	0.7	1.1	2.1	0.00^{b}	0.7	0.3	1.6	1.6	2.7	0.6	2.0	0.2
3.8, Select	6.6	2.0^{b}	0.9	0.8	2.3	0.04^{ab}	0.4	0.2	1.8	1.5	2.7	0.3	2.1	0.3
Temperature °C x Quality Grade														
177, T. Choice	6.5	1.7	1.2	1.2	2.0	0.05	0.8	0.4	1.7	1.5^{ab}	1.8	0.7	0.3	0.0
177, Select	6.3	1.5	1.2	0.9	2.2	0.03	0.5	0.3	2.0	1.5^{ab}	1.8	0.4	0.4	0.1
232, T. Choice	6.5	2.1	0.7	1.1	2.1	0.00	0.5	0.3	1.6	1.6^{a}	2.6	0.5	2.0	0.2
232, Select	6.4	1.9	0.8	0.9	2.2	0.03	0.3	0.2	1.8	1.5^{b}	2.6	0.3	2.0	0.2
RMSE	0.36	0.51	0.46	0.32	0.25	0.08	0.35	0.20	0.29	0.25	0.65	0.27	1.14	0.29

[abcd]Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$). [1]Aroma measured where 0 = none and 15 = extremely intense.

Table 3 (con't). Beef flavor attributes[1] least squares means for USDA Select and Top Choice beef top loin steaks across grill temperature and steak thickness

Treatment	Juiciness	Muscle Fiber Tenderness	Connective Tissue Amount	Overall Tenderness
P > F				
Thickness	0.62	0.001	0.26	0.001
Grill Temperature	0.93	0.12	0.47	0.12
Quality Grade	0.25	0.33	0.53	0.33
Thickness x Temp.	0.97	0.74	0.71	0.74
Thickness x QG	0.81	0.78	0.41	0.78
Temperature x QG	0.09	0.27	0.98	0.27
Thickness (cm) x Temperature °C				
1.3, 177	10.5	11.6	12.2	11.6
1.3, 232	10.5	11.4	12.1	11.4
3.8, 177	10.4	11.2	12.3	11.2
3.8, 232	10.4	11.0	12.3	11.0
Thickness (cm) x Quality Grade				
1.3, T. Choice	10.6	11.6	12.2	11.6
1.3, Select	10.4	11.4	12.1	11.4
3.8, T. Choice	10.5	11.2	12.3	11.2
3.8, Select	10.4	11.1	12.3	11.1
Temperature °C x Quality Grade				
177, T. Choice	10.6	11.5	12.3	11.5
177, Select	10.3	11.3	12.2	11.3
232, T. Choice	10.4	11.2	12.2	11.2
232, Select	10.5	11.2	12.2	11.2
RMSE	0.60	0.61	0.51	0.61

[abcd]Mean values within a column and effect followed by the same letter are not significantly different (*P* > 0.05).
[1]Aroma measured where 0 = none and 15 = extremely intense

Table 4. Least squares means for consumer attributes[1] for USDA Select and Top Choice beef top loin steaks across grill temperature and steak thickness.

Treatment	Overall liking	Overall flavor liking	Beef flavor liking	Grill flavor liking	Juiciness liking	Tenderness liking
P > F						
Thickness	0.001	0.001	0.14	0.51	0.15	0.001
Grill Temp.	0.001	0.001	0.001	0.004	0.001	0.002
Quality Grade	0.081	0.068	0.14	0.02	0.13	0.13
Thick.x Temp.	0.001	0.001	0.001	0.001	0.008	0.06
Thickness x QG	0.86	0.50	0.49	0.83	0.49	0.69
Temp.x QG	0.46	0.84	0.66	0.86	0.99	0.59
Thickness (cm) x Temperature °C						
1.3, 177	6.3[a]	6.4[a]	6.5[b]	5.9[b]	6.2[ab]	6.6
1.3, 232	6.4[a]	6.5[a]	6.5[b]	6.3[a]	6.1[b]	6.5
3.8, 177	6.6[a]	6.6[a]	6.9[a]	6.5[a]	6.4[a]	6.2
3.8, 232	5.6[c]	5.6[c]	6.0[c]	5.6[c]	5.7[c]	5.8
Thickness (cm) x Quality Grade						
1.3, T. Choice	6.5	6.5	6.6	6.2	6.3	6.6
1.3, Select	6.3	6.4	6.5	6.0	6.1	6.4
3.8, T. Choice	6.1	6.2	6.5	6.1	6.1	6.1
3.8, Select	6.0	6.1	6.4	6.0	6.0	6.0
Temperature °C x Quality Grade						
177, T. Choice	6.5	6.6	6.8	6.3	6.4	6.5
177, Select	6.4	6.5	6.7	6.1	6.2	6.3
232, T. Choice	6.1	6.2	6.3	6.0	6.0	6.2
232, Select	5.9	6.0	6.2	5.9	5.8	6.1
RMSE	1.98	2.01	1.91	2.06	2.18	2.13

[abc]Mean values within a column followed by the same letter are not significantly different (*P* > 0.05).

[1]Attributes measured where 0 = dislike extremely and 9 = like extremely

Table 5. Least squares means for chemical components for USDA Select and Top Choice beef top loin steaks.

Effect	Non-Heme iron, mg/g	Myoglobin mg/g	Moisture %	Lipid %
P > F	0.001	0.045	0.001	0.001
T. Choice top loin steaks	1.97[b]	1.42	71.66[b]	6.16[a]
Select top loin steaks	3.42[a]	2.06	73.53[a]	4.02[b]
RMSE[f]	0.87	0.86	1.47	1.65

[a,b] Mean values within a column and effect followed by the same letter are not significantly different (*P* > 0.05).

Table 6. Least squares means for fatty acid components for USDA Select and Top Choice beef top loin steaks.

Effect	14:0	14:1	16:0	16:1	18:0	18:1	18:1 vacc	18:2	18:3	20:0	20:1	20:4
Polar lipids												
P > F	0.17	0.35	0.87	0.29	0.95	0.009	0.16	0.06	0.12	-	-	0.33
T. Choice top loin steaks	1.55	1.29	24.43	2.62	14.95	37.62[a]	1.39	6.95	0.14	-	-	1.88
Select top loin steaks	1.10	1.66	24.31	2.40	14.89	33.15[b]	1.72	9.04	0.32	-	-	2.25
RMSE	0.50	0.91	2.02	0.57	2.47	4.19	0.61	2.81	0.029	-	-	0.96
Neutral lipids												
P > F	0.97	0.25	0.83	0.84	0.095	0.005	0.32	0.014	0.40	0.49	0.40	0.13
T. Choice top loin steaks	1.75	1.38	26.37	2.82	16.09	41.46[a]	1.29	2.38[a]	0.12	0.11	0.32	0.18
Select top loin steaks	1.74	2.14	26.05	2.87	14.32	35.20[b]	1.44	3.29[b]	0.14	0.09	0.18	0.35
RMSE	0.83	1.29	3.64	0.63	2.53	4.97	0.36	0.84	0.027	0.025	0.086	0.11

[a,b] Mean values within a column and effect followed by the same letter are not significantly different (*P* > 0.05).

Table 7. Overall means (n=218) and standard deviation values for volatile, aromatic chemicals identified by the GC/MS.

Code	Compound	Mean	Std Dev
1	1 octen 3 ol	41643	135047
2	1-butanol	742	5922
3	1-Butanol, 3-methyl-	1955	21070
4	1-decanol	1016	7222
5	1-decene	993	10755
6	1-dodecanamine	63	447
7	1-dodecanol	951	3670
8	1-heptanol	49173	88331
9	1-hexanol	23979	59639
10	1-hexanol, 2-ethyl-	4548	17245
11	1-nonanol	2296	8779
12	1-octanol	114273	129153
13	1-octen-3-ol	106549	410924
14	1-octen-3-one	1549	8816
15	1-octene	1459	9834
16	1-pentanol	2260	16205
17	1-tetradecanol	758	7397
18	1-tridecanol	325	2765
19	1-undecanol	993	4075
20	1,1-Dodecanediol, diacetate	1666	11784
21	1,3-Benzenediol, monoacetate	139	1083
22	1,3-Hexadiene, 3-ethyl-2-methyl-	503	4179
23	1,3-Hexadiene, 3-ethyl-2-methyl-, (Z)-	205	1910
24	1,3-octadiene	526	3599
25	1H-Imidazole, 4-(2-propenyl)-	1026	7302
26	1h-pyrrole	1187	6997
27	1H-Pyrrole-2-carboxaldehyde	79	633
28	1H-Pyrrole-2-carboxaldehyde, 5-methyl-	123	790
29	1H-Pyrrole, 1-ethyl-	350	2683
30	2 octenal	26763	49312
31	2-acetyl thiazole	3228	9598
32	2-Acetyl-2-thiazoline	1108	4190
33	2-Acetyl-3-methylpyrazine	381	1477
34	2-allyl-5-methylpyrazine	1081	5045
35	2-allyl-6-methylpyrazine	527	5506
36	2-Aminoethyl hydrogen sulfate	1332	9217

Table 7. (con't) Overall means (n=218) and standard deviation values for volatile, aromatic chemicals identified by the GC/MS.

Code	Compound	Mean	Std Dev
37	2-butanone	28804	93397
38	2-Butanone, 3-hydroxy-	13498	77571
39	2-butylfuran	221	1267
40	2-citronellyl-3,6-dimethylpyrazine	147	1247
41	2-decanone	25816	44382
42	2-decenal, (e)-	50570	72731
43	2-dococen-1-al	6411	31750
44	2-dodecanone	651	3555
45	2-dodecenal	379	3123
46	2-dodecene, (z)-	233	2318
47	2-furancarboxaldehyde	2631	9840
48	2-Furancarboxaldehyde, 5-methyl-	364	1527
49	2-furanmethanol	2152	6726
50	2-heptanone	9419	27344
51	2-Heptanone, 6-methyl-	866	5375
52	2-heptenal (Z and E)	23880	95006
53	2-hexanone	457	2698
54	2-hexenal	464	2098
55	2-Isopentyl-3-methylpyrazine	657	5980
56	2-methyl pyrazine	12528	69128
57	2-n-Heptylfuran	419	2504
58	2-nonanone	17463	30823
59	2-nonenal	14083	20789
60	2-octanone	11048	23202
61	2-octenal, (e)-	22466	87254
62	2-octylfuran	1468	5796
63	2-pentanone	1872	9039
64	2-Pentanone, 4-hydroxy-4-methyl-	4027	12602
65	2-Pentanone, 4-methyl-	110	867
66	2-propanone	9018	22847
67	2-Propanone, 1-(acetyloxy)-	353	2498
68	2-Propanone, 1-phenyl-	101	899
69	2-tridecanone	1950	13279
70	2-undecanone	2021	7156
71	2-Undecanone, 6,10-dimethyl-	614	2669
72	2-undecenal	6295	26297
73	2,3-butanedione	19193	36916

Table 7. (con't) Overall means (n=218) and standard deviation values for volatile, aromatic chemicals identified by the GC/MS.

Code	Compound	Mean	Std Dev
74	2,3-dimethylbenzaldehyde	49	376
75	2,3-octanedione	69399	230999
76	2,3-pentanedione	254	1979
77	2,3,5-trimethyl pyrazine	2763	25872
78	2,3,5-Trimethyl-6-ethylpyrazine	1718	9563
79	2,4 decadienal	3114	11839
80	2,4-nonadienal, (e,e)-	726	4037
81	2,5-hexanedione	378	4153
82	2,5-octanedione	6536	29214
83	2(3H)-Furanone, 5-heptyldihydro-	335	1922
84	2(3H)-Furanone, 5-hexyldihydro-	92	715
85	2(3H)-Furanone, dihydro-	831	6152
86	2(3H)-Furanone, dihydro-5-pentyl-	351	2782
87	2(5h)-furanone	1047	4333
88	3-Cyclohepten-1-one	2671	20989
89	3-dodecen-1-al	13221	33637
90	3-furaldehyde	1007	5008
91	3-heptanol	987	6615
92	3-Heptanol, 4-methyl-	363	2342
93	3-heptanone	385	2202
94	3-n-butylcyclopentanone	460	2813
95	3-octanol	566	2905
96	3-octanone	2356	14645
97	3-Penten-2-one, 4-methyl-	2036	11187
98	3,4-dihydropyran	1298	6858
99	4-ethyl-2,5,6-trimethylpyrimidine	2514	10608
100	4-octanone	2709	13975
101	4-Octen-3-one	728	5312
102	5 methyl furfural	129	1010
103	5-decanone	341	3398
104	5-methyl--6,7-dihydro-(5h)-cyclopentapyrazine	284	1009
105	5-nonanone	473	3790
106	5h-5-methyl-6,7-dihydrocyclopenta[b]pyrazine	89	708
107	Acetaldehyde	3810	9956
108	Acetic acid	30861	50132
109	Acetic acid ethenyl ester	368	3247
110	Acetic acid, decyl ester	236	2254

Table 7. (con't) Overall means (n=218) and standard deviation values for volatile, aromatic chemicals identified by the GC/MS.

Code	Compound	Mean	Std Dev
111	Acetone	1868	9319
112	Acetophenone	1806	10274
113	Acetylpyrrole	879	4989
114	Aloxiprin	1266	6996
115	Benzaldehyde	1940813	1467961
116	Benzaldehyde, 3-ethyl-	413	3140
117	Benzene, 1-ethyl-4-methyl-	1435	13558
118	Benzene, 1,3-bis(1,1-dimethylethyl)-	6725	21793
119	Benzene, ethyl-	71	779
120	Benzene, methyl-	7434	61018
121	Benzene, propyl-	1437	4933
122	Benzeneacetaldehyde	23324	40151
123	Benzenemethanol	1551	4771
124	Benzoic acid, 4-hydroxy-	108	838
125	Benzonitrile	122	970
126	Butanal	1523	8473
127	Butanal, 2-methyl-	44581	87974
128	Butanal, 3-methyl-	54498	100340
129	Butane, 1-(ethenyloxy)-	32	269
130	Butanoic acid	8022	28041
131	Butyrolactone	138	1082
132	Carbon disulfide	6461	16592
133	Carbonic acid, butyl ester octyl ester	569	4409
134	Chavicol	227	1516
135	Cyclohexane, methyl-	251	2397
136	Cyclohexene, 3-(1-methylethyl)-	598	5332
137	Cyclopentanol	179	1279
138	Cyclopentanone, 3-butyl-	845	4203
139	Decanal	121467	137888
140	Decane, 2-methyl-	265	2417
141	Decane, 2,2-dimethyl-	290	2249
142	Decane, 2,5,6-trimethyl-	1706	17908
143	Decanoic acid	286	1438
144	Dimethyl sulfide	373	2192
145	Dodecanal	20309	56093
146	Dodecane	71414	192263
147	Eicosane, 10-methyl-	230	1794

Table 7. (con't) Overall means (n=218) and standard deviation values for volatile, aromatic chemicals identified by the GC/MS.

Code	Compound	Mean	Std Dev
148	Ethane, (methylthio)-	395	1931
149	Ethanone, 1-(1H-pyrrol-2-yl)-	5954	16133
150	Ethanone, 1-(2-furanyl)-	727	4559
151	Ethanone, 1-(2-pyridinyl)-	406	2477
152	Ethanone, 1-(4,5-dihydro-2-thiazolyl)-	7270	10080
153	Ethanone, 1-phenyl-	4378	13318
154	Formic acid, hexyl ester	1100	7112
155	Formic acid, octyl ester	2798	16055
156	Furan, 2-pentyl-	81302	216224
157	Furfural	360	2804
158	Heptanal	28587	156829
159	Heptane	8183	42918
160	Heptanoic acid	2021	10857
161	Heptanol	791	6443
162	Heptenal	2273	8826
163	Hexadecane	746	4052
164	Hexanal	1975876	3821187
165	Hexane, 2,2,5-trimethyl-	449	2861
166	Hexanoic acid	15057	25530
167	Linalool	203	1309
168	Methane, thiobis-	457	2111
169	Methanethiol	4880	11595
170	N heptanal	427225	722589
171	N-Caproic acid vinyl ester	14515	64554
172	Nonacosane	284	1623
173	Nonadecane	1280	5902
174	Nonanal	1484968	1385745
175	Nonenal	36301	65112
176	Octacosane	111	784
177	Octadecane	569	5006
178	Octanal	642499	492777
179	Octane	3018	25071
180	Octane, 2,2-dimethyl-	199	1629
181	Octenal	1485	8351
182	Oxalic acid, isobutyl heptyl ester	3385	19316
183	Oxazole, 2-hexyl-4,5-dimethyl-	186	1735
184	Oxirane, phenyl-	1225	9118

Table 7. (con't) Overall means (n=218) and standard deviation values for volatile, aromatic chemicals identified by the GC/MS.

Code	Compound	Mean	Std Dev
185	Pentadecane	947	5039
186	Pentanal	65815	210700
187	Pentanoic acid	660	3696
188	Phenol	741	4448
189	Phenol, 4-methyl-	4082	11067
190	Phenyl acetaldehyde	5249	14434
191	Propanal, 2-methyl-	2787	24680
192	Propanal, 3-(methylthio)-	4824	15798
193	Pyrazine, 2-ethyl-3,5-dimethyl-	982	5063
194	Pyrazine, 2-ethyl-5-methyl-	29966	79267
195	Pyrazine, 2-ethyl-6-methyl-	35067	64863
196	Pyrazine, 2-methyl-5-(1-propenyl)-, (E)-	433	4586
197	Pyrazine, 2-methyl-5-(2-propenyl)-	634	4248
198	Pyrazine, 2-methyl-6-(1-propenyl)-, (E)-	400	2884
199	Pyrazine, 2,3-diethyl-5-methyl-	296	2093
200	Pyrazine, 2,3-dimethyl-	20713	52384
201	Pyrazine, 2,5-dimethyl-	169367	222680
202	Pyrazine, 2,5-dimethyl-3-(3-methylbutyl)-	2047	6399
203	Pyrazine, 3-ethyl-2,5-dimethyl-	93204	118170
204	Pyrazine, methyl-	18189	56318
205	Pyrazine, trimethyl-	143288	199005
206	Pyridine	673	5508
207	Styrene	38298	62544
208	Sulfur dioxide	1461	8460
209	Tetradecanal	9077	27706
210	Tetradecane	1714	11244
211	Tetradecane, 2,6,10-trimethyl-	274	1781
212	Thiourea	1471	6027
213	Trans-2-Undecen-1-ol	1481	9230
214	Tridecanal	7238	21205
215	Tridecane	12606	31276
216	Undecanal	35473	67748
217	Undecane	12536	41073
218	Undecenal	25334	58427

Table 8. Classification of volatile chemicals by type and area under the curve total ion counts for thickness and temperature treatment.

	Thickness, cm			Temperature, °C			
Volatile Chemical	1.3	3.8	*P* > F	177	232	*P* > F	RMSE
Alkanes							
1-(ethenyloxy)-butane	0	145	**	4	51	NS	257
Dodecane	12808	129862	*	83302	59368	NS	192257
Ethoxy-ethene	0	10322	*	3640	2002	NS	23168
Heptane	0	17352	NS	14850	1635	*	42929
Octane	11247	0	*	6277	519	NS	24300
Pentadecane	1675	151	NS	138	1688	*	4971
Aldehydes							
2-hexenal	626	330	NS	798	157	*	2069
2-nonenal	10642	16914	NS	10341	17215	*	21110
2 octenal	7148	42565	**	29596	22117	NS	47698
3-dodecen-1-al	15215	10974	NS	7526	18662	*	33726
5-methyl-1H-pyrrole-2-carboxaldehyde	0	435	**	10	208	NS	740
Acetaldehyde	8482	0	**	4214	3646	NS	9780
Decanal	72405	167054	**	91147	148312	**	135304
(e)-2-decenal	51462	47376	NS	33148	65690	**	70645
Hexanal	1008036	2884231	NS	2640815	1251452	**	3779410
Octenal	2278	616	NS	2936	0	**	8401
Pentanal	5719	121675	*	95396	31998	*	207977
Phenyl acetaldehyde	5229	5733	NS	8683	2279	**	14811
Undecanal	21348	48479	NS	12419	57407	**	65070
Ketones							
1-(1H-pyrrol-2-yl)-ethanone	2198	8737	NS	7925	3009	*	15737
1-(2-pyridinyl)-ethanone	469	315	NS	0	794	*	2429
1-(4,5-dihydro-2-thiazolyl)-ethanone	12426	2535	**	9002	5959	*	9349
1-octen-3-one	0	4330	*	2995	0	*	8665
2-decanone	15126	36494	NS	12190	39429	**	42623
2-nonanone	10332	3183	NS	8055	25460	**	28617
2-octanone	8658	13347	NS	6074	15930	**	22561

Table 8. (Con't) Classification of volatile chemicals by type and area under the curve total ion counts for thickness and temperature treatment.

	Thickness, cm			Temperature, °C			
Volatile Chemical	1.3	3.8	*P* > F	177	232	*P* > F	RMSE
2-propanone	10659	8041	NS	13061	5639	*	22712
2,3-octanedione	6386	128321	NS	109233	25474	**	227784
3-butyl-cyclopentanone	1852	161	NS	0	1707	**	4129
3-heptanone	1192	0	**	0	807	**	2135
3-n-butylcyclopentanone	980	0	NS	0	940	*	2800
3-penten-2-one, 4-methyl-	5207	0	*	4348	97	**	10626
3-octanone	1321	3197	NS	2.5	4516	*	14650
4-octanone	0	10407	*	1344	6614	NS	22045
4-hydroxy-4-methyl-2-pentanone	6229	1209	NS	5520	1918	*	10990
6,10-dimethyl-2-undecanone	797	473	NS	1174	96	**	2649
Acetone	0	4789	**	1313	2142	NS	9213
Alcohols							
1-butanol	2579	0	*	514	1080	NS	5843
1 octen 3 ol	34638	49125	NS	70734	13029	**	134358
2-(hexyloxy)-ethanol	364831	77658	**	278238	164250	**	320210
2-ethyl-1-hexanol,	11285	0	**	7460	2277	*	16055
Benzenemethanol	2477	617	NS	488	2605	**	4531
Chavicol	691	0	*	247	241	NS	1511
Acids							
Ethyl allophanate	0	124	**	40	22	NS	274
N-caproic acid vinyl ester	0	41618	**	22689	4631	NS	63078
Pyrazines							
2-Acetyl-3-methyl-pyrazine	669	77	NS	93	653	**	1458
2-allyl-5-methyl-pyrazine	0	2417	*	296	1715	NS	4887

Table 8. (Con't) Classification of volatile chemicals by type and area under the curve total ion counts for thickness and temperature treatment.

	Thickness, cm			Temperature, °C			
Volatile Chemical	1.3	3.8	*P* > F	177	232	*P* > F	RMSE
2-ethyl-5-methyl-pyrazine	24804	38544	NS	4277	59070	**	72468
2-ethyl-6-methyl-pyrazine	14405	55339	**	24756	44988	*	60443
2,3-diethyl-5-methyl-pyrazine	136	693	NS	0	838	*	2520
2,5-dimethyl-3-(3-methylbutyl)-pyrazine	2019	1859	NS	818	3061	**	6425
3-ethyl-2,5-dimethyl-pyrazine	79370	102200	NS	67903	113668	**	110226
3,6-dimethyl-2-pentylpyrazine	609	0	**	92	251	NS	1344
Methyl-pyrazine	11948	29994	NS	6556	35387	**	59547
Trimethyl-pyrazine	84538	200682	*	113239	171981	*	191003
Furans							
2-butylfuran	582	0	*	95	363	NS	1225
2-furancarboxaldehyde	4184	1093	NS	882	4395	**	9557
2-furanmethanol	0	4854	**	179	4537	**	6772
2-n-heptylfuran	324	721	NS	0	1056	**	2784
2-octylfuran	346	2420	NS	0	2770	**	5537
2-pentyl-furan	18460	141578	*	109754	50284	NS	213355
5-heptyldihydro-2(3H)-furanone	0	1105	**	23	581	*	1868
5-methyl-2-furancarboxaldehyde	541	159	NS	22	678	**	1475
Sulfur-containing							
Dimethyl sulfide	1000	0	*	543	257	NS	2175
Methanethiol	0	11251	**	6454	3679	NS	11301
Methylthio-ethane	3	931	NS	0	939	**	2038
Thiourea	0	3484	**	2246	658	NS	5930

Table 8. (Con't) Classification of volatile chemicals by type and area under the curve total ion counts for thickness and temperature treatment.

	Thickness, cm			Temperature, ^{o}C			
Volatile Chemical	1.3	3.8	*P* > F	177	232	*P* > F	RMSE
Benzenes							
1,3-bis(1,1-dimethylethyl)-benzene	16527	0	**	7577	6536	NS	20032
2,4,6-trimethyl-1,3-benzenediamine	263	550	NS	0	820	**	2131
Methyl-benzene	0	26885	**	5327	8241	NS	60911
Other							
1h-pyrrole	709	1575	NS	0	2328	*	6677

** = ($P < 0.01$)
* = ($P < 0.05$)

Table 9. Stepwise linear regression for prediction of consumer overall like as the dependent variable and Volatile Chemicals as independent variables.

Variables	Estimate[a] x 10^{-6}	Partial R^2	Equation R^2
Intercept	5.66		
methylthio ethane,	212.00	0.0597	0.06
Phenol	-99.43	0.0187	0.08
2-butanone	-1.84	0.0119	0.09
Acetic acid	10.05	0.0261	0.12
2-undecanone	-28.64	0.0091	0.13
Cyclopentanol	-164.00	0.0085	0.13
Pentanal	-3.58	0.0094	0.14
Nonanal	0.53	0.0177	0.16
Decanal	-4.34	0.0068	0.17
Undecanal	4.29	0.0066	0.17
Pyrazine, 2-ethyl-5-methyl-	3.39	0.0070	0.18
2,5,6-trimethyl-4-ethylpyrimidine	-28.62	0.0111	0.19
Carbon disulfide	10.50	0.0063	0.20
Phenyl acetaldehyde	15.85	0.0059	0.20
2,4 decadienal	18.72	0.0066	0.21
Pentanoic acid	43.68	0.0065	0.22
3-(1,1-dimethylethyl)-2,2,4,4-tetramethy	-12.63	0.0047	0.22
Thiourea	20.77	0.0040	0.23

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 10. Stepwise linear regression for prediction of consumer flavor like as the dependent variable and Volatile Chemicals as independent variables.

Variables[a]	Estimate[a] x 10^{-6}	Partial r^2	Equation r^2
Intercept	6.06		
Ethane, (methylthio)-	158.00	0.0432	0.04
2-Undecanone	-30.86	0.0140	0.06
Phenol	-54.42	0.0124	0.07
2-Butanone	-3.85	0.0091	0.08
Acetic acid	7.34	0.0140	0.09
chavicol	-133.00	0.0078	0.10
3-Furaldehyde	37.54	0.0068	0.11
Carbon disulfide	16.68	0.0070	0.11
2-Furancarboxaldehyde	22.60	0.0065	0.12
2-Aminoethyl hydrogen sulfate	-29.36	0.0063	0.13
Pentane, 2,2,3,4-tetramethyl-	-44.00	0.0063	0.13
2-Heptanone, 6-methyl-	28.04	0.0053	0.14
trans-2-Undecen-1-ol	-29.55	0.0048	0.14
5h-5-methyl-6,7-dihydrocyclopenta[b]pyrazine	214.10	0.0058	0.15
Octanal	0.31	0.0050	0.15

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 11. Stepwise linear regression for prediction of consumer beef flavor as the dependent variable and Volatile Chemicals as independent variables.

Variables		Estimate[a] x 10^{-6}	Partial r^2	Equation r^2
	Intercept	6.28		
	2-n-Heptylfuran	-132.00	0.0306	0.03
	2-Aminoethyl hydrogen sulfate	-30.00	0.0151	0.05
	2-Furancarboxaldehyde	19.80	0.0146	0.06
	chavicol	-152.00	0.0086	0.07
	Acetic acid	7.26	0.0097	0.08
	Pentanal	-1.64	0.0154	0.09
	3-Pentanol, 3-(1,1-dimethylethyl)-2,2,4,4-tetramethyl-	-21.82	0.0078	0.10
	Ethanone, 1-(4,5-dihydro-2-thiazolyl)-	17.40	0.0079	0.11
	Tridecane	-4.65	0.0083	0.12
	Pyrazine, 3-ethyl-2,5-dimethyl-	3.26	0.0056	0.12
	Pyrazine, 2-methyl-5-(2-propenyl)-	-32.72	0.0047	0.13
	2,3,5-trimethyl pyrazine	-5.28	0.0046	0.13
	Aloxiprin	18.37	0.0038	0.14
	Carbon disulfide	8.73	0.0036	0.14
	Styrene	-3.59	0.0043	0.14
	Benzene, 1,2-dichloro-	00.02	0.0033	0.15

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 12. Stepwise linear regression for prediction of beef flavor identity as the dependent variable and aromatic volatile compounds as independent variables.

Variables	Estimate[a] x 10^{-6}	Partial r^2	Equation r^2
Intercept	6.47		
1-Hexanol, 2-ethyl-	-6.84	0.073	0.07
1,1-Dodecanediol, diacetate	-8.62	0.050	0.12
1-Undecanol	-27.00	0.045	0.17
1H-Pyrrole-2-carboxaldehyde, 5-methyl-	131.5	0.048	0.21
1,3-Octadiene	25.9	0.044	0.25
2-Pentanone, 4-hydroxy-4-methyl-	-10.3	0.033	0.28
Butanal, 3-methyl-	1.14	0.057	0.33
2-Butanone, 3-hydroxy-	-1.06	0.043	0.37
Octacosane	-96.90	0.026	0.40
2-methyl pyrazine	-3.41	0.025	0.42
Butanoic acid	6.00	0.089	0.47
Eicosane, 10-methyl-	45.40	0.046	0.49
2-Octanone	3.32	0.026	0.51

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 13. Stepwise linear regression for prediction of brown/roasted as the dependent variable and aromatic volatile compounds as independent variables.

Variables	Estimate[a] x 10^{-6}	Partial r^2	Equation r^2
Intercept	1.97		
Ethanone, 1-(4,5-dihydro-2-thiazolyl)-	-27.7	0.120	0.12
Butanal, 2-methyl-	1.15	0.050	0.17
Octane, 2,2-dimethyl-	-88.9	0.050	0.22
5-methyl--6,7-dihydro-(5h)-cyclopentapyrazine	222.4	0.040	0.26
1,3-octadiene	43.1	0.030	0.29
Benzoic acid, 4-hydroxy-	205.8	0.030	0.32
Pyrazine, 2-ethyl-5-methyl-	2.52	0.020	0.34
2(5h)-furanone	32.4	0.030	0.37
Butyrolactone	111.3	0.020	0.39
Cyclopentanone, 3-butyl-	25.5	0.030	0.42
Benzaldehyde	-0.148	0.030	0.45
Hexanoic acid	7.48	0.020	0.47
1-butanol	0.030	0.500	0.50
2-Acetyl-2-thiazoline	-30.9	0.020	0.52
5h-5-methyl-6,7-dihydrocyclopenta[b]pyrazine	176.3	0.030	0.55

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 14. Stepwise linear regression for prediction of bloody/serumy as the dependent variable and aromatic volatile compounds as independent variables.

Variables	Estimate[a] x 10^{-6}	Partial r^2	Equation r^2
Intercept	0.910		
2-methyl-butanal	-1.419	0.089	0.09
1-(4,5-dihydro-2-thiazolyl)-ethanone	10.666	0.039	0.16
2-Octanone	-5.426	0.053	0.20
2-Propanone	4.2373	0.031	0.24
1-Pentanol	9.4918	0.080	0.27
Phenyl-oxirane	10.735	0.033	0.30

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 15. Stepwise linear regression for prediction of descriptive sensory fat-like flavor as the dependent variable and aromatic volatile compounds as independent variables.

Variables	Estimate[a] x 10^{-6}	Partial r^2	Equation r^2
Intercept	1.11		
Decanoic acid	-6.2	0.079	0.08
Pyrazine, 2-ethyl-6-methyl-	-1.054	0.057	0.14
5-Decanone	46.5	0.025	0.20
2-Octanone	-3.508	0.122	0.24
3-Penten-2-one, 4-methyl-	-6.576	0.032	0.27
2(3H)-Furanone, 5-heptyldihydro-	-34.2	0.040	0.30
Butanal, 3-methyl-	0.58592	0.031	0.33
4-Ethyl-2,5,6-Trimethylpyrimidine	-6.267	0.025	0.35

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 16. Stepwise linear regression for prediction of descriptive sensory metallic flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Variables	Estimate[a] x 10^{-6}	Partial r^2	Equation r^2
Intercept	2.099		
Octenal	-20.0	0.078	0.08
Formic acid, octyl ester	6.51	0.091	0.17
2-Furanmethanol	14.9	0.057	0.23
1-Dodecanamine	193.2	0.059	0.29
Dimethyl sulfide	26.0	0.041	0.33
2-Pentanone, 4-methyl-	71.0	0.038	0.36
Ethanone, 1-(2-furanyl)-	10.8	0.035	0.40
2(3H)-Furanone, dihydro-	-9.70	0.034	0.43
1,3-Octadiene	-14.7	0.031	0.46
2-Acetyl-2-thiazoline	-10.8	0.027	0.49
1-Pentanol	2.61	0.023	0.51
Hexadecane	-10.2	0.021	0.53

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 17. Stepwise linear regression for prediction of descriptive sensory liver flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Variables	Estimate[a] x 10^{-6}	Partial r^2	Equation r^2
Intercept	-0.000951		
1-decene	4.94	0.248	0.44
Chavicol	12.70	0.047	0.51
2,5-hexanedione	5.94	0.074	0.56
2-Butanone, 3-hydroxy-	0.36	0.078	0.60
Cyclohexane, methyl-	6.64	0.036	0.65
Ethanone, 1-(2-furanyl)-	4.53	0.063	0.68
Sulfur dioxide(DOT)	-2.73	0.040	0.71
2,3-butanedione	0.47	0.037	0.73
Dodecane	0.209	0.103	0.75
N heptanal	-0.036	0.038	0.79
1-heptanol	-0.14	0.010	0.81
Ethanone, 1-(4,5-dihydro-2-thiazolyl)-	1.42	0.025	0.82
5h-5-methyl-6,7-dihydrocyclopentapyrazine	-23.50	0.027	0.84
3-octanone	0.84	0.018	0.85
1,1-Dodecanediol, diacetate	0.67	0.008	0.86
Trans-2-Undecen-1-ol	1.02	0.007	0.86
2-nonenal	-0.35	0.007	0.87
Linalool	-5.34	0.006	0.87

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 18. Stepwise linear regression for prediction of descriptive sensory umami flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Variables	Estimate[a] x 10^{-6}	Partial r^2	Equation r^2
Intercept	0.668		
2-Octylfuran	-16.80	0.062	0.07
Benzene, 1,3-bis(1,1-dimethylethyl)-	-4.51	0.063	0.11
Pyrazine, 2-ethyl-6-methyl-	-1.61	0.070	0.17
Octacosane	-113.00	0.052	0.21
Tetradecane, 2,6,10-trimethyl-	-37.30	0.029	0.24

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 19. Simple correlation coefficients among cooking parameters and trained sensory panel descriptive attributes.

	Beef ID	Brown/ Roasted	Bloody/ Serumy	Fat-like	Metallic	Livery	Umami
Initial grill temperature	0.096	0.224	-0.408	-0.133	0.001	-0.167	-0.214
Steaks surface temperature at flipping	0.239	0.241	-0.284	-0.089	0.013	-0.079	-0.046
Grill temp-erature at flipping	0.102	0.184	-0.322	-0.109	-0.030	-0.082	-0.135
Grill time on 1st side	0.519	0.459	-0.147	-0.093	0.182	-0.166	0.127
Grill time on 2nd side	0.360	0.379	-0.180	-0.185	0.138	-0.032	0.006
Total grill time	0.503	0.481	-0.189	-0.162	0.183	-0.111	0.074
Final steak surface temp-erature	0.307	0.367	-0.435	-0.180	0.059	-0.086	-0.118
Final grill temperature	0.163	0.253	-0.444	-0.205	0.063	-0.199	-0.215
Cook loss, %	0.154	0.184	-0.072	-0.232	0.087	-0.147	-0.062

F values > 0.18 or < - 0.18 are significant

APPENDIX B

FIGURES

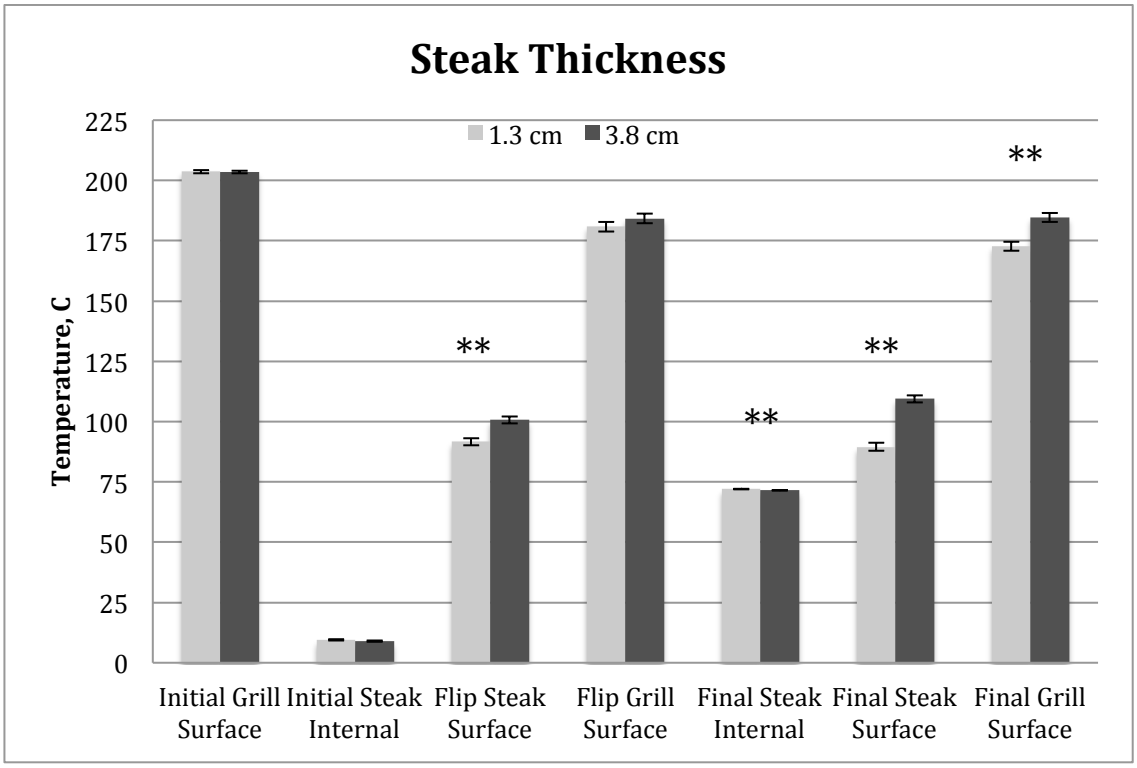

Figure 1. Steak thickness effects on steak and skillet temperatures. ** Indicates significant ($P < 0.05$) treatment differences.

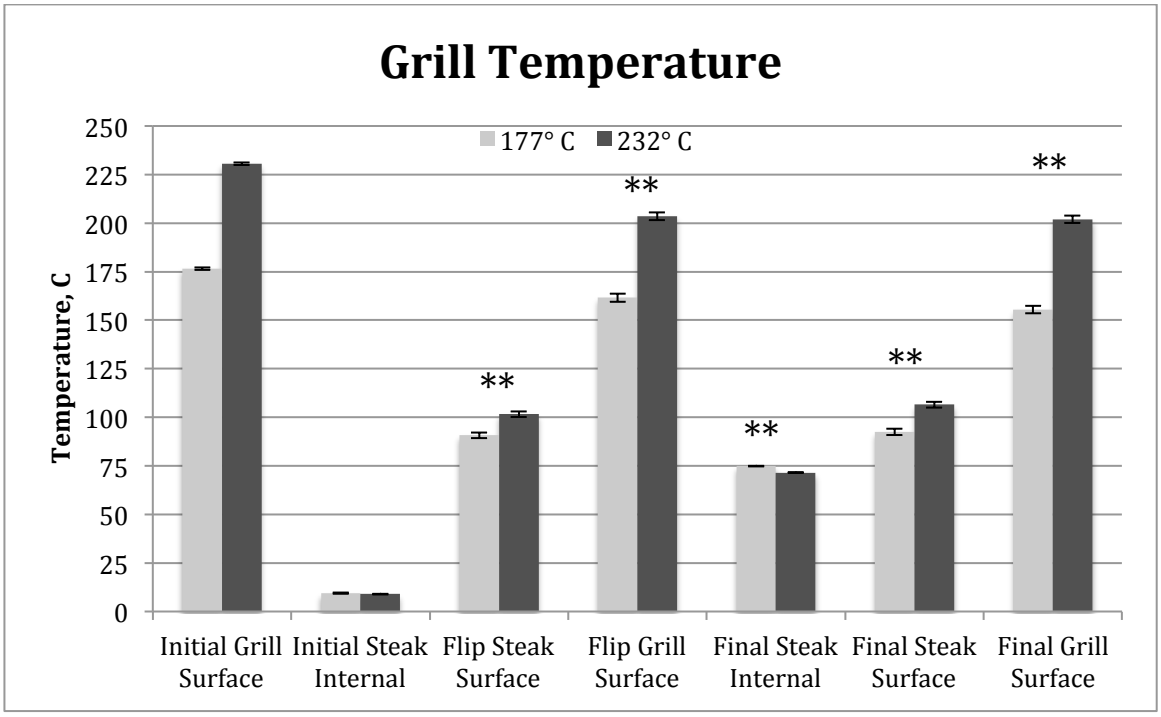

Figure 2. Cooking surface temperature effects on steak and skillet temperatures. ** Indicates significant ($P < 0.05$) treatment differences.

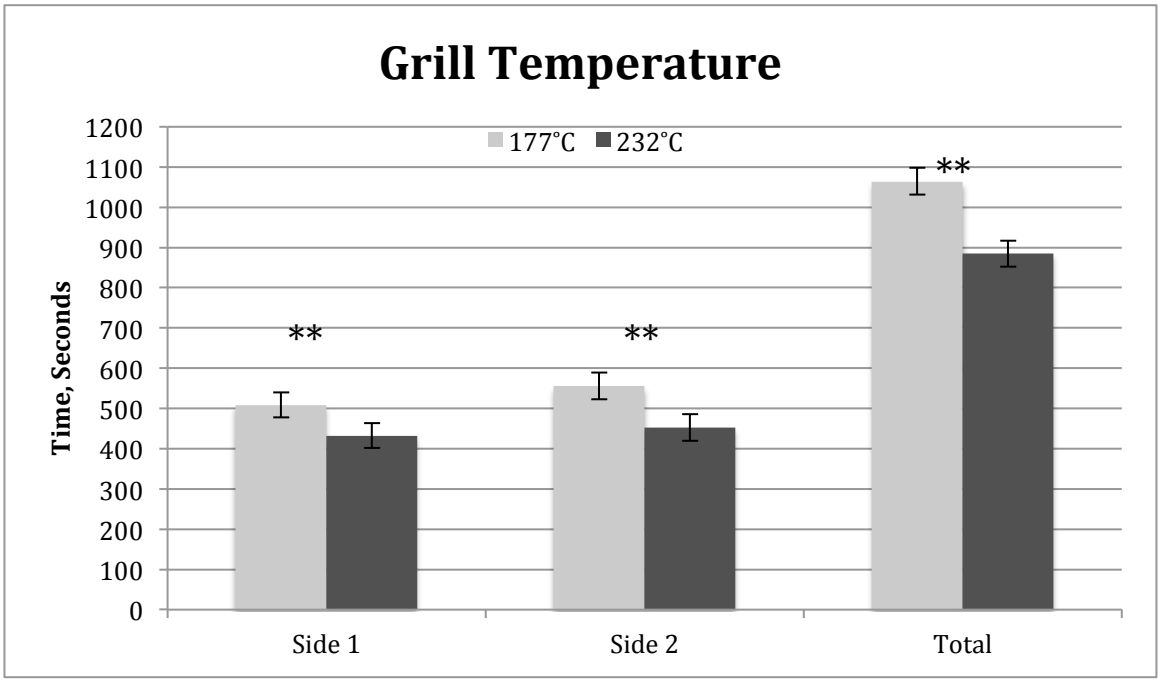

Figure 3. Cooking surface temperature effects on cooking time. ** Indicates significant ($P < 0.05$) treatment differences.

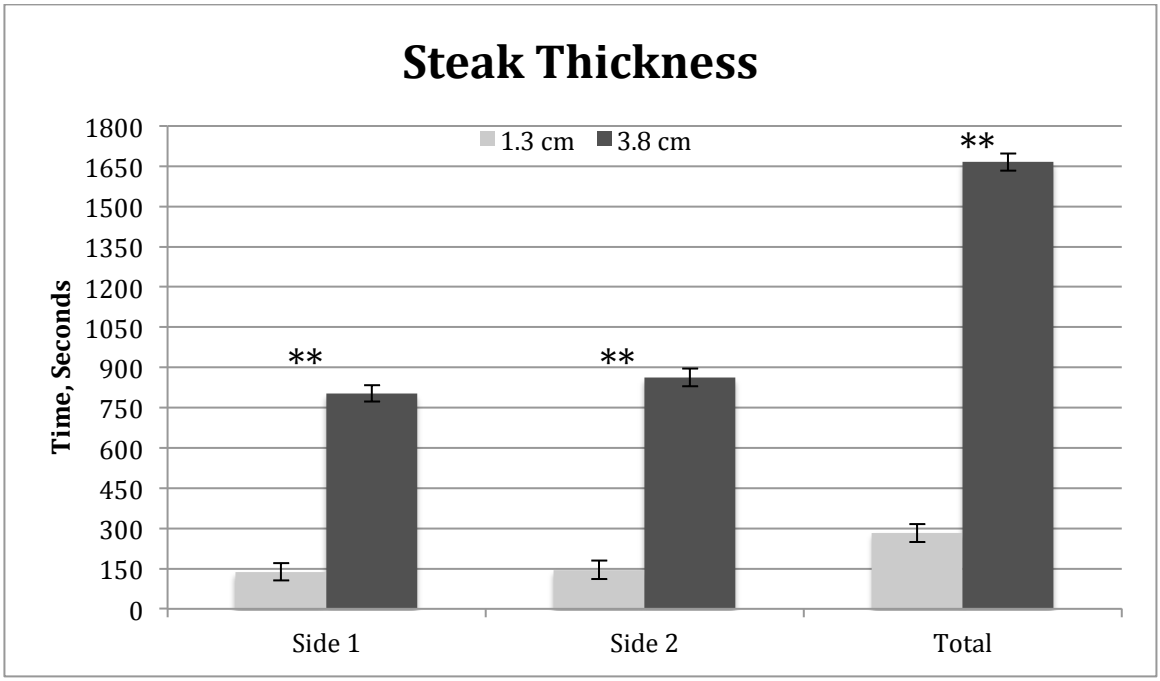

Figure 4. Steak thickness effects on cooking time. ** Indicates significant ($P < 0.05$) treatment differences.

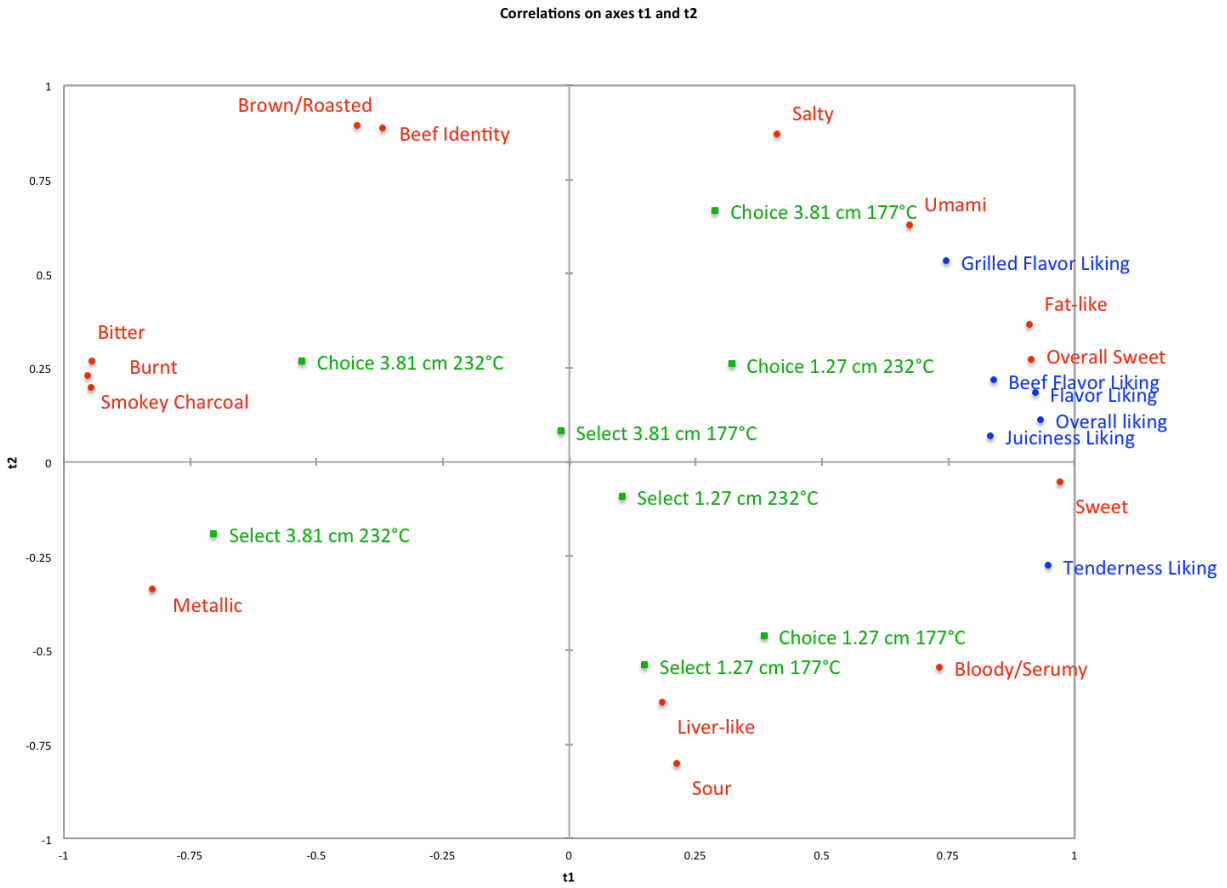

Figure 5. Partial least squares regression biplot of trained descriptive flavor attributes from the Beef Lexicon (in red), consumer sensory attributes (in blue), and treatments (in green).

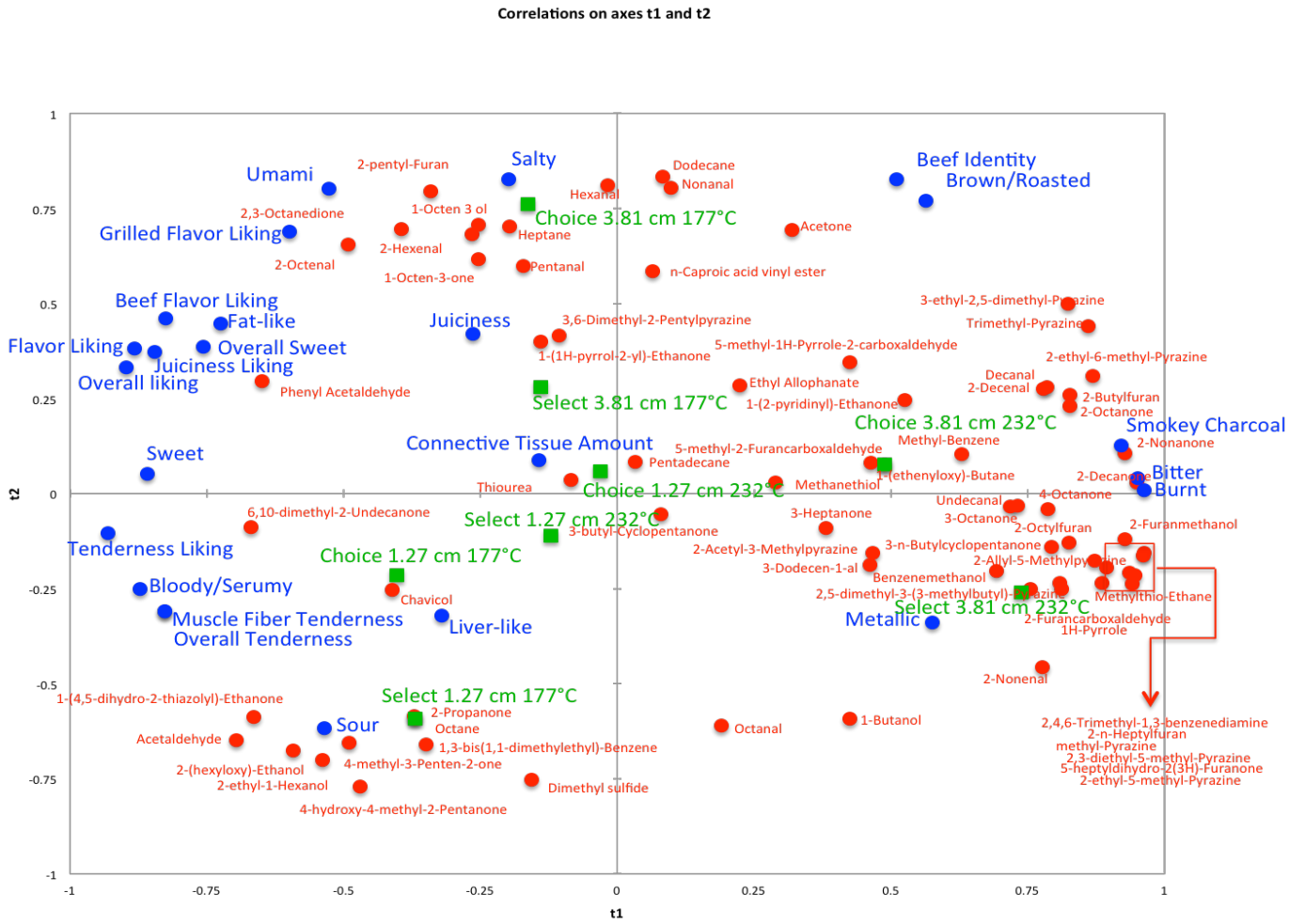

Figure 6. Partial least squares regression biplot of trained descriptive flavor attributes from the Beef Lexicon and consumer sensory attributes (in blue), 71 volatile aromatic compounds (in red) and treatments (in green).

APPENDIX C

CONSUMER FORMS

INSTRUCTIONS

Thank you for your participation in this study. Your assistance is very much appreciated. The objective of this study is to evaluate beef samples. Please take your time and evaluate the samples given to you carefully. Please proceed at your own rate.

This sampling will take you about one hour and you will be eating **8** total samples. Please answer the following questions as completely as possible. If you have any questions, please ask the monitor for assistance.

Begin by filling out the basic demographic questions on the first page. This information is confidential and will not be used to solicit advertising nor will this information be published with your name associated with it.

After filling out the demographic information you are ready to start the evaluation. **BOLD LETTERS** throughout the questionnaire will give you directions on how to complete the evaluation.

Thank you very much for your help and opinions.

DEMOGRAPHIC INFORMATION

Please circle each appropriate response.

1. Please indicate your gender.
   Male Female
2. Which of the following best describes your age?
   20 years or younger
   21 - 25 years
   26 - 35 years
   36 - 45 years
   46 - 55 years
   56 - 65 years
   66 years and older
3. Please specify your ethnicity.
   African-American
   Asian/Pacific Islanders
   Caucasian (non-Hispanic)
   Latino or Hispanic
   Native American
   Other
4. Which of the following best describes your household income?
   Below $25,000
   $25,001 - $49,999
   $50,000 - $74,999
   $75,000 - $99,999
   $100,000 or more
5. How many people live in your household including yourself?
   1 2 3 4 5 6 or more
6. Please indicate your employment level.
   Not employed Part-time Full-time
7. Please circle any of the following proteins that you eat either at home or at a restaurant (away from home). **At Home** **Away from Home/Restaurant**

Chicken	Chicken
Beef	Beef
Pork	Pork
Fish	Fish
Lamb	Lamb
Eggs	Eggs
Soy Based Products	Soy Based Products

8. How many times a week total do you consume the following protein sources?

Beef	0	1-2	3-4	5-6	7 or more
Pork	0	1-2	3-4	5-6	7 or more
Lamb	0	1-2	3-4	5-6	7 or more
Chicken	0	1-2	3-4	5-6	7 or more
Fish	0	1-2	3-4	5-6	7 or more
Soy Based Products	0	1-2	3-4	5-6	7 or more

9. What cooking method do you prefer to use when cooking a beef steak? Circle any that apply.

Pan-frying or using a skillet on the stove	Stir Fry
Grilling Outside	Oven Broiling
Oven Baking	Microwave
Electric Appliance (George Foreman Grill or other electric grill)	

10. At what temperature do you typically set the cook surface (grill, pan, oven, etc.)?

Lower than 350°F 350°F 400°F 450°F Higher than 450°F

12. What degree of doneness to you prefer your steak to be cooked to?

Rare Medium Rare Medium Medium Well Well Very Well

11. When purchasing beef, what thickness do you prefer to buy at the retail store?

less than ½ inch ½ inch 1 inch 1 ½ inch Thicker than 1 ½ inch

13. When purchasing beef, what do you typically tend to buy at the retail store?

Grass Fed beef Dry Aged Organic Traditional at the retail store

14. What flavor or types of cuisines do you like, please circle all that apply?

American	Barbeque	Mexican/Spanish	Indian
Chinese	Greek	Japanese	Italian
French	Thai	Lebanese	

Consumer Form 1. Consumer Demographics

Please take a bite of cracker followed by a sip of water prior to evaluating the product. Place a mark in the box that represents your answer for each of the following questions.

1. How much do you like or dislike this meat OVERALL?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely				Neither Like or Dislike				Like Extremely

2. How much do you like or dislike of the OVERALL FLAVOR of this steak?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely				Neither Like or Dislike				Like Extremely

3. How much do you like or dislike of the BEEFY FLAVOR of this steak?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely				Neither Like or Dislike				Like Extremely

4. How much do you like or dislike of the GRILLED FLAVOR of this steak?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely				Neither Like or Dislike				Like Extremely

5. How much do you like or dislike of the JUICINESS of this steak?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely				Neither Like or Dislike				Like Extremely

6. How much do you like or dislike of the TENDERNESS of this steak?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely				Neither Like or Dislike				Like Extremely

7. Please write any words that describe the POSITIVE or GOOD FLAVORS in this steak.

_____

8. Please write any words that describe the NEGATIVE or BAD FLAVORS in this steak.

_____

Consumer Form 2. Consumer Ballot